Optimizing Coordination Strategies in a Real Supply Chain: Simulation Approach

Von der Fakultät für Ingenieurwissenschaften, Abteilung Maschinenbau der
Universität Duisburg-Essen
zur Erlangung des akademischen Grades

DOKTOR-INGENIEUR

genehmigte Dissertation

von

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Tag der mündlichen Prüfung: 12.09.2007

ABSTRACT OF THE DISSERTATION

In recent years the interest in the supply chain coordination field has been growing, both among companies and researchers, particularly in the area of transportations systems and logistics management. Many companies realize that coordinating supply chain activities can maximize the performance of the supply chain, through the minimization of the system-wide costs while still satisfying service level requirements. The coordination of inventory and distribution (transportation) activities are the effective key for efficient coordination of the supply chain. Therefore, this dissertation deals mainly with developing new coordination distribution strategies that coordinate the inventory and transportation activities and optimize the performance of the supply chain. These strategies are evaluated and their applications are reported using the real-life supply chain network which motivated this research. In this dissertation, a real life food Supply Chain company located in a European country was considered for more detailed studies. Since the real supply chain being modeled and the problem of coordinating two activities are so complex that optimal solutions are very hard to obtain, most of the study models consider simple networks and make many assumptions to simplify the problem, for example, considering only one item in a static inventory system. Thus, it can be solved by exact algorithms (mixed integer programming) and heuristic solution approaches.

Generally to solve such coordinated problems optimally is not easy due to its combinatorial nature, especially when many strategies are involved. Simulation models that permit user interaction and take into account the dynamics of the system are capable of characterizing system performance for coordinated and integrated models.

A discrete simulation model integrated with C++ program was constructed specifically for modeling this real supply chain. The simulation model was

validated by comparing the simulation results with the real data provided by the company. Then the simulation is extended to model and implement the new coordination distribution strategies. The new strategies are designed based on new trends and a new prescriptive of the Supply Chain. To show the importance and the value of the coordination strategies, uncoordinated strategies which were designed based on the item classification approaches (ABC & XYZ classifications) are presented and implemented by the developed simulation model. These uncoordinated strategies are evaluated to compare them with the developed new coordination strategies. The new trends which are considered in designing the coordination strategies are, for example, the shipment consolidation concepts, advance demand information technology, and vendor managed inventory (VMI) programs. All the mentioned trends are implemented and realized in this work.

This dissertation presents two new shipment consolidation concepts for constructing new coordination distribution strategies. These two are the "Item classification consolidation concept" and "N-days forecasted demand consolidation concept". The first consolidation concept is developed based on the item classification concept and the second consolidation concept is developed based on the advance demand information technology. The problems such as the residual stock resulting from applying or using the coordination strategies are interpreted and discussed. Moreover, these two consolidation concepts are integrated with the VMI programs to construct more appropriate and efficient coordination strategies between the inventory policies and transportation strategies.

To evaluate the effectiveness of the coordination strategies, a number of measures of performance have been selected. These measures are the logistics costs and the customer satisfaction (responsiveness/backorders). Many simulation results are collected and analyses have been made. These results and analyses show that under the right conditions the value of coordination can be extremely high. Also, the simulation results show that, the coordination strategies are better than the uncoordinated strategies for optimizing the system performance. Furthermore, the newly developed coordination strategies which incorporate the appropriate shipment consolidation concepts, advanced information technology, and apply new initiatives like VMI programs, are capable of reducing the system-wide costs and improving the Supply Chain performances significantly. Finally, conclusions and suggestions for future research have been presented.

Dedication

TO

My mother, Halima
My father, Prof. Ali
My wife, Ing. Khadiga
My daughter Ala
My daughter Arig
My daughter Farah
My brothers and my sisters

Tarak Ali Housein

Acknowledgments

I wish to express my sincere gratitude to my supervisor Prof. Dr.-Ing. Bernd Noche, for the may inspirational discussions and guidance throughout this work.

Special thanks to all academic and technical staff of Transportsysteme und –logistik Institute for their many helpful suggestions and technical supports.

I wish to acknowledge my gratitude to the SimulationsDienstleistungsZentrum GmbH for their support especially in applied simulation and optimization methods for simulation studies for real life application.

Another special gratitude owes to my wife, from whom I always get support and lovely care especially during my study here in Germany.

At last but not least, I would like to thank my family (mother, father, brothers, and sisters) for their support all the way from the very beginning of my study.
I am thankful to all my family members for their thoughtfulness and encouragement.

Duisburg, September 2007

Tarak Ali Housein

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1. Introduction

1.1. Definition of Supply Chain

Supply chain management (SCM) has been recently presented to address the coordination and integration of organizational functions, ranging from the supply and receipt of raw materials throughout the manufacturing stages, to the distribution and delivery of final products to the end customer. Its application demonstrates that this idea enables companies to achieve higher quality products, better customer service, and lower inventory and transportation costs. In order to achieve high system performance, supply chain functions (processes) must operate in an integrated and coordinated manner.

The SCM literatures offer many definitions and frameworks of a supply chain [MDK01], [Tan01], [LGC05], [SB06]. Beamon [Bea98] defined a supply chain as an integrated manufacturing process herein raw materials are converted into final products and then delivered to customers. At its highest level, a supply chain is comprised of two basic and integrated processes: (1) Production Planning and Inventory Control Process and (2) Distribution and Logistics Process. These processes are illustrated below in Figure 1.

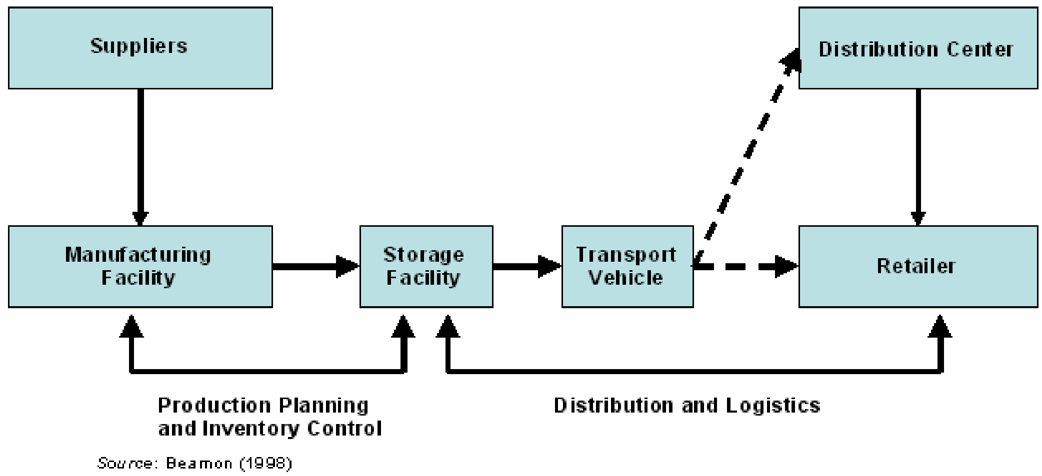

Figure 1. 1 The Supply Chain Process

According to Simchi-Levi et al. [SKS03], a supply chain is "*a set of approaches utilized to efficiently integrate suppliers, manufactures, warehouses, and stores, so that merchandise is produced and distributed at the right quantities, to right locations, and at the right time, in order to minimize systemwide costs while satisfying service level requirements*".

As stated by Ballou [Bal04], "*The supply chain encompasses all activities associated with the flow and transformation of goods from the raw materials stage (extraction), through to the end user as well as the associated information flows. Materials and information flow both up and down the supply chain. Supply chain management (SCM) is the integration of these activities, through improved supply chain relationships, to achieve a sustainable competitive advantage".*

Nilsson [Nil6] summarized the new trends in the SCM and logistics as discusses by Waters [Wat03]. There are 12 different trends in logistics today. These are:

- *Improving communications.* Better communication within the supply chain with new technologies such as Electronic Data Interchange (EDI).

- *Improving customer service*. Making logistics cost as low as possible and increasing high service levels at low costs.
- *Globalization.* Firms operations are becoming more and more international when trade and competition are rising.
- *Reduced number of suppliers.* The number of suppliers is reduced and long term relationships are created.
- *Concentration of ownership*. When the companies experience economics of scale the competition is concentrated to fewer players on the market.
- *Outsourcing.* More and more logistics operations are outsourced to specialized companies.
- *Postponement.* The movement of almost-finished goods into the distribution system and delays of final modifications.
- *Cross-docking*. When incoming goods are shipped again without being stored at the warehouse.
- *Direct delivery.* Direct shipping from manufacturer to final customer.
- *Other stock reduction methods.* Newer methods such as Just-in-Time and Vendor Managed Inventories.
- *Increasing environmental concerns.* The movement towards 'greener' practices among logistics operations.
- *More collaboration along the supply chain.* Aiming towards the same objectives and no internal competition within the supply chain.

This thesis is based on three of the logistics trends outlined above; improving customer service, *cross-docking* and *other stock reduction methods*. Procuring several items from upstream locations to downstream locations in supply chains requires well functioning coordination regarding transportation and inventory decisions, and therefore, this thesis deals mainly with the common problems of transportation and inventory coordination.

1.2. Coordination in Supply Chains

Supply chain consists of many systems including manufacturing, storage, transportation, and retail systems. Managing of any one these systems involves a series of complex trade-offs. Additionally, these systems are connected and hence the outputs from one system within the supply chain are the inputs to the next system. For example the outputs from the production system may be the inputs to a transportation or inventory system. Therefore the various systems need some kind of coordination to operate effectively.

Coordinating supply chain activities maximises the supply chain performance [SKS03]. Supply chain coordination improves if all the stages of the chain take actions that altogether increase total supply chain profits. Supply chain coordination requires each stage of the supply chain to take into account the impact its actions have on other stages.

A coordination mechanism is a set of methods used to manage the interactions between multiple supply chain tiers. To increase the high-performance of supply chain, an organization should select the appropriate coordination mechanism [XB06]. A lack of coordination occurs either because different stages of the supply chain have objectives that may conflict, or because information moving between different stages may have been distorted [CM04].

The management of the entire supply chain has become possible in the recent years due to new developments in the technology of information systems. But still it is obviously much more difficult than dealing with each of the traditional production, transportation and inventory decision problems separately.

In spite of the difficulty in managing a supply chain, the coordination of inventory polices and transportation strategies are the key terms for an efficient management of the supply chain. Transportation strategies include the application of different types of shipment consolidation (freight consolidation) policies. The consolidation policy coordinates the shipping of different item orders for the same destination, and this can lead to a reduction in transportation costs. Higginson and Bookbinder [HB94] present a simple discrete-event simulation model to distinguish between three types of consolidation policies: the time policy, the quantity policy and the time-and-quantity policy. The time policy dispatches orders at a scheduling shipping date. The quantity policy dispatches orders when a fixed consolidated quantity is reached. The time-and-quantity policy is a mixed policy of the time and the quantity policies. Instead of using simulation, Higginson and Bookbinder [HB95] use a Markov chain model to determine the optimal consolidation policy given as an (s,S) continuous review inventory policy generating shipment orders, where s is reorder point and S is order-up-to level. In this thesis, a new shipment consolidation concept (quantity policy) based on item classification approach is developed and a discrete-event simulation model to test this concept for effective coordination is developed.

With recent advances in communication and advanced information technology, companies have better chance for substantial savings in the total logistics costs by coordinating and integrating the different stages in the supply chain. Clearly, companies realize that the sharing of information through the supply chain is beneficial. As is already known, to coordinate and integrate the supply chain effectively, the information must be available and shared. Several information technologies (IT) have been developed recently in order to facilitate this. Electronic data interchange (EDI), the Internet, and Web sites are some of these technologies. By applying these technologies, many new supply chain initiatives, such as Vendor Managed Inventory (VMI), are constructed and implemented.

VMI is a coordination mechanism in which the upstream member of the supply chain manages the inventory level and the appropriate inventory policies on its downstream member of the supply chain. In VMI, one can optimize the entire system performance by coordinating inventory and distribution. As suggested by Silver et al. [SPP98], the VMI is one of the new future developments in supply chain initiatives that could be expanded as the next competitive source of supply chain coordination. Therefore in this thesis, the VMI is implemented for a real life supply chain to see the benefits of using this approach on the coordination of supply chains and how this approach can be incorporated effectively to develop a new coordination strategy. Furthermore, the most important requirement for an effective coordination, especially for a VMI, is advance demand information.

Contemporary research has been conducted on how a supplier can make use of customer demand information for better demand forecasts and inventory control policies [GKT96], [CF00], [LST00], [AF98]. In industry, there has been great interest expressed in the concept of a supplier making use of downstream demand information to coordinate the replenishments or shipments [CL02]. Here, coordinating the shipment is the practice used by the supplier in order to make the timing and quantity of replenishment decisions for the retailers, the advance demand information being provided by the retailers [CL02]. In this thesis, a new shipment consolidation concept (quantity policy) that uses the advance demand information technology for consolidating shipments is developed. For effective coordination between the inventory and transportation decisions and for optimizing of the real supply chain, this concept is linked to VMI programs.

In reality supply chains are complex and consist of numerous companies. The companies have different complex network structures. These companies realize that great savings of the total logistics cost can be obtained by effective designing of the supply chain network and distribution strategies.

1.3. Motivation

This thesis was motivated by a real life food supply chain company located in a European country. This company wanted to optimize its supply chain network and the distribution strategies.

The supply chain distribution network model that should be analyzed is typically complex; it considers many strategies to be changed over time. The mathematical optimization techniques have some limitations as they deal only with static models. However, simulation based tools which take into account the dynamics of the system are capable of characterizing system performance for a given design.

In this research, the distribution network simulation model was created by using DOSIMIS-3, with support of C++ program it was specifically developed for the supply chain simulation purpose. Some other tools were customized for use with this particular model. The validation of the simulation model has been done by comparing the simulated results with the historical data obtained from the logistic department of the company. Therefore, in this thesis, the simulation model is extended to include and to implement all aspects of the new prescriptive of supply chains that have been discussed. Another motivation is the availability of significant amount of historic data (more variations and dynamic) from the company’s ERP system which has been used to conduct all the simulation studies in this thesis.

1.4. Outline of the Thesis

The thesis consists of eight chapters. These chapters are organized as follows: Chapter 1 gives a brief introduction on the supply chain and supply chain coordination. Chapter 2 gives a survey of the existing literatures in the fields to overview the variations of the integrated problems in supply chains and supply chain simulation. In this chapter, the goals of the dissertation are presented. Chapter 3 deals with simulation modeling of supply chains. The chapter on simulation modeling of supply chains gives an overview of the various activities involved in the supply chain. This chapter discusses in detail the description of the developed simulation model. The chapter also discusses the procedure and tools adopted for carrying out the simulation. The various features of the simulation model including the performance measures are also explained. The real life problem is presented and explained in this chapter. Extend studies on the real life case study are also described, the logic methodology and the steps of the two new consolidation concepts are also explained. An in depth description of the implementation of the coordination strategies and VMI concept using the developed simulation model is also given in this chapter.

Chapter 4 deals with the designing and the conducting of the uncoordinated strategies based on the item classification approaches. Two item classification approaches (ABC & XYZ) are presented in this chapter. The detailed description of the designing, resulting, and analysis of the experiments are also presented in this chapter. The main measures of performance used in this thesis are also described in this chapter. In Chapter 5, description of how to design and conduct the coordination strategies using the two new consolidation approaches is presented. All the results and analysis of the results of the coordination experiments are also presented in this chapter. Chapter 6 presents the optimization of coordination strategies by using a newly developed item classification. This new item classification is explained in this chapter. The new coordination strategies developed based on this new classification are also described. Results and analysis of these new strategies are summarized and illustrated in this chapter. In Chapter 7, the use of the Vendor-Managed Inventory (VMI) programs for constructing optimal coordination strategies is described and presented. Comparative studies are conducted and exhibited in this chapter. Finally, Chapter 8 summarizes the results and conclusions with some recommendations which would be useful for future studies.

2. Literature Review

A large body of literature exists on the coordination and integrated supply chains. This chapter gives an outline of the literature reviewed for the purposes of this work. In Section 2.1, a review of the literature on supply chain coordination is given. Section 2.2 discusses supply chain simulation frameworks that have been proposed in the past. Section 2.3 deals with goals of the dissertation.

2.1. Overview of various approaches on the coordination and integrated problems in supply chains

Several approaches can be found in the literature, which provide models to coordinate at least two stages of the supply chain and which can detect new opportunities that may exist for improving the efficiency of the supply chain. Beginning with Clark and Scarf in 1960 [CS60], many researchers have considered multi-echelon distribution-inventory problems. This problem considers a central plant (warehouse) that allocates a product (or products) to a number of customers with the objective of minimizing overall total costs including holding cost and transportation cost [AF90], [AF90], [FZ84]. The decision variables which have been considered in the problem are shipment sizes and delivery routes.

A large amount of researches has been conducted on the inventory-distribution coordination [DB87], [Cha93]. Anily and Federgruen [AF90] have studied a model integrating inventory control and transportation planning decisions motivated by the trade-off between the size and the frequency of delivery. They have considered a single-warehouse and multi-retailer scenario where inventory would be kept only at the retailers that face constant demand. The model determines the replenishment policy at the warehouse and the distribution schedule for each retailer so that the total inventory and distribution costs are minimized. They have presented heuristic procedures to find upper and lower bounds on the optimal solution value.

Bhatnagar et al. [BCG93] classified the issue of coordination in organizations in to two problems. The first problem is the General Coordination problem (coordination between functions) and the second problem is the Multi-Plant Coordination problem (coordination within the same function at different echelons in an organization). They study the Multi-Plant Coordination problem. The authors have presented a good categorization and some literature review for the general coordination problem. Within this problem they have distinguished three categories that represent the integration of decision making pertaining to: (1) supply and production planning, (2) production and distribution planning, and (3) inventory and distribution planning.

Thomas and Griffin [TG96] defined three categories of the operational coordination of the supply chain management. These three categories are: (1) Buyer-vendor coordination, (2) Production-distribution coordination, (3) Inventory-distribution coordination. Also they have made a review study on the supply chain coordination and list some topics for future work.

Viswanathan and Mathur [VM97] studied the same problem as Anily and Federgruen [AF90] with the generalization of multiple products in the system. They have developed a heuristic based on a joint replenishment problem to obtain a stationary nested joint replenishment policy (SNJRP). They have considered vehicles with limited capacity and present computational results comparing the performance of the proposed heuristic with the heuristics proposed by Anily and Federgruen [AF90], for the case of a single product. Their results show that the SNJRP policy performs better in the majority of cases in terms of cost. The authors have reported that no other heuristic was known to handle multiple products. Therefore, a comparison was not possible for problems that consider more than one product in the system.

Sarmiento and Nagi [SN99] presented a review on the integrated analysis of production-distribution systems, and have identified important areas where further research would be needed. They have suggested that further research in the Inventory/Distribution problem could take into consideration more complex networks for analysis. Algorithms that explicitly consider the location of several customers and depots, as well as the routing of vehicles and inventory levels setting are needed for more complete dynamic scenarios. While optimal solutions are very difficult to obtain, heuristic procedures could be developed to obtain approximate solutions for this complex problem. Validation methods would also be required. Research is also needed for the explicit consideration of multiple products in the system. The analysis of different instances of the Inventory/Distribution problem under stochastic demand considerations is still a largely open research area. Further research is also needed for Inventory/ Distribution scenarios that would acknowledge the existence of emergency shipments, and would consider a constrained transportation system.

Morales [Mor00] studied a class of optimization models, which would integrate both transportation and inventory decisions, to search for opportunities for improving the logistics distribution network. He considered a set of plants and a set of warehouses to deliver the demand to the customers, he proposed a class of greedy heuristics, and showed that significant improvements could be made by using the result of the greedy heuristic as the starting point of two local exchange procedures, yielding very nearly optimal solutions for problems with many customers.

Yang [Yan00] considered a single- warehouse multiple-retailer (SWMR) system. His work is one of the first to examine the relative impact of various policies and environmental factors on the performance of an SWMR system. He suggested three important environmental factors and four policies that may affect the performance of an SWMR system. The three environmental factors are: the number of stores, order processing time and demand variability. The four policies are: the warehouse location, vehicle-scheduling rule, inventory rule and order size.

He has developed a simulation model of an SWMR system using SLAM II. The simulation result shows that the number of stores, demand variability, order size and order processing time have a much larger impact on the performance than the inventory and vehicle-scheduling rules. This paper also provides some suggestions for future research. The environmental factors, for instance, have demonstrated a much larger impact on the performance than the inventory and vehicle-scheduling rules. Future research should therefore examine the impact of the environmental factors in greater details, such as the impact of variable order processing times. Another possible area for future research is a detailed comparison between the Continuous Review and Periodic Review policies.

Min and Zhou [MZ02] offered an effort to help firms capture the synergy of inter-functional and inter-organizational integration and coordination across the supply chain and subsequently make better supply chain decisions. This effort is based on the prior supply chain modelling efforts. They present the models that attempt to integrate different functions of the supply chain as the supply chain models. Such models deal with the multi-functional problems of location/routing, production/distribution, location/inventory control, inventory control/transportation, and supplier selection/ inventory control.

Liu [Liu03] concluded that most of the integrated production-distribution models consider transportation elements as a fixed cost, and no routing or other transportation capacity issues are involved. In other words, these models consider only the demand allocation element in distribution, and make decision based only on how much product has to be transported from production plant to customers. There is no decision on how the transportation function is carried out. Most of these models, with few exceptions, do not consider how these quantities can be transferred by transporters with their capacity, speed, and availability (constrained time to operate). Based on that Liu [Liu03] proposed and evaluated the effectiveness of a two-phase solution methodology for solving the integrated production, inventory and distribution problem (PIDP) where the transporters routing must be optimized together with the production lot sizes and the inventory policies. The phase I model, a PIDP with direct shipment, is solved as a mixed-integer programming problem subject to all the constraints in the original model, except that the transporters routings are restricted to direct shipment. To handle the potential inefficiency of the direct shipment, Phase II applies a heuristic procedure (the Load Consolidation (LC) algorithm) to solve an associated consolidation problem. The associated delivery consolidation problem is formulated as a capacitated transportation problem with additional constraints. In this capacitated transportation problem, transporters in the heterogeneous fleet are allowed to make multiple trips per period. His study on this problem enriches the existing literature of Vehicle Routing Problem (VRP), and the proposed LC algorithm provides an alternative to solve complicated real life distribution problems with a heterogeneous fleet that allows multiple trips per transporters. There are several potential extensions from this work. Firstly, from a practical point of view, models that allow the distribution centre (DC) demands to be random variables and that some DC's to be used as transshipment points could be of great value to real world needs. Secondly, there have been a vast amount of research results available for capacitated vehicle routing. A comparative study of the LC algorithm used in Phase II of this study with existing heuristics in the literature results has a potential to further improve the solution quality of the approaches to the integrated production, inventory and distribution routing problems. Finally, he assumes that each plant owns a fixed fleet of heterogeneous transporters, and that the transporters owned by one plant do not travel to other plants.

Mason et al. [MRF03] examined the total cost benefit that could be achieved by suppliers and warehouses through the increased global visibility provided by an integrated system. They developed a discrete event simulation model of a multi-product supply chain to examine the potential benefits to be gained from global inventory visibility, trailer yard dispatching and sequencing techniques. From the simulation results they showed that queue dispatching rules significantly affect total cost, by assigning the sequence of loading and unloading trucks. Queue dispatching rules also aid cross-docking, which significantly reduces holding and back-ordering costs. They suggested for future research that in order to quantify operational improvements resulting from the implementation of an integrated system. It would be necessary to establish a set of metrics to ensure that overall supply chain costs are reduced, rather than simply optimizing the various components of the supply chain individually. Potential issues to be considered include the coordination of replenishment when a single vendor supplies multiple SKUs (Stock Keeping Unit), so that full-truckload trucking can be utilized. When a pull system is implemented, initially ordered quantities are smaller due to existing safety stock. This may result in less than full-truckload trucking. However, assuming that demand does not decrease, as soon as the system exhausts the safety stock, the system should reach equilibrium and reverts back to full-truckload trucking.

Another line of research in coordination of supply chain is the joint replenishment or coordinated replenishment problem. The Joint Replenishment Problem (JRP) is a research topic in the area of multi-item inventory problems that has been generating interest for many years as it is a common real-world problem that occurs in different situations, for instance, when a group of items are replenished from the same supplier or when a product after manufacturing is packaged in different quantities. Goyal [Goy73], [Goy74] gives a more detailed definitions and descriptions of the problem.

Goyal and Satir [GS89] presented an early review of all models, starting from a simple deterministic problem. In the joint replenishment literature, two types of control policy were presented. These are: the continuous review can-order policy (s_i, c_i, S_i) and the periodic review order-up-to policy (R_i, S_i). In the continuous can-order policy (s_i, c_i, S_i), when the inventory position of an item i reaches the must-order point s_i, replenishment is triggered as to raise the item's inventory position to order-up-to level S_i. Meanwhile, any other item in the group with an inventory position at or below its can-order point c_i is included in the replenishment as to raise the inventory position up to S_i [LY00], [FGT84]. In the periodic review policy (R_i, S_i), the inventory position of item i is inspected with intervals R_i and the review moments are coordinated in order to consolidate orders of individual items [VM97].

Silver et al. [SPP98] explained the cost savings that can be achieved by coordinating the replenishment of several items. Sombat et al. [SRE05], Chen and Chen [CC05], and Nilsson [Nil06] give a more detailed information on the JRP and associated issues. As can be seen from literature, due to the difficulty of coordination problems, most of the models proposed are analytical models which consider simple supply chain networks, therefore, they limit more investigations on the supply chain coordination. Rather simulation models can be used to handle and analyse complex problems. Figure 2.1 summarizes the classification of supply chain coordination as presented in the lite7rature.

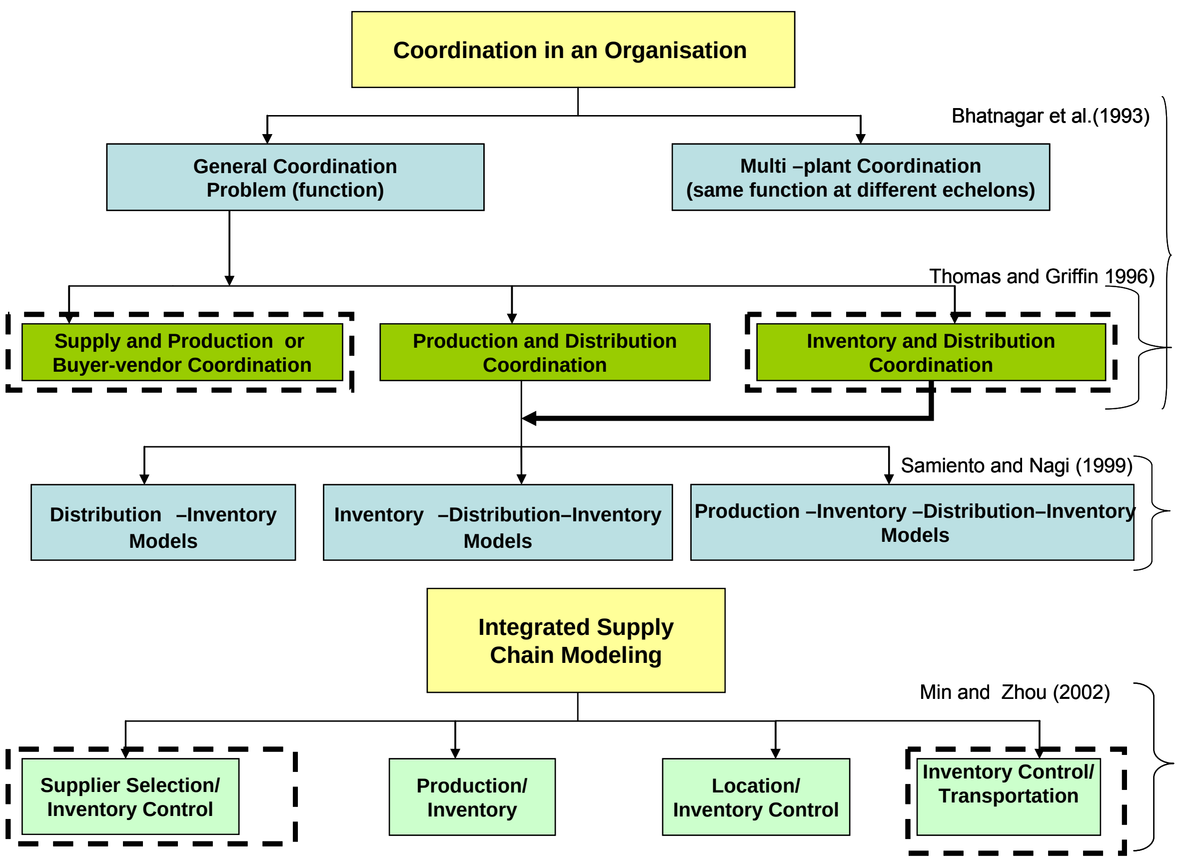

Figure 2. 1 Classification of Supply Chain Coordination

The dashed boxes in the above figure indicate the points of focus of this thesis.

2.2. Overview of the supply Chain Simulation

There are extensive literatures available on the analysis of supply chain coordination. Two of the most common ways of analyzing a supply chain are simulation and analytical modeling. The literature on the analytical modeling is presented in the previous section. This section summarizes some of the significant research on supply chain simulation.

Cachon and Fisher [CF97] examined forecasting and inventory management under VMI for Campbell's Soup. Using simulations of their ordering rules, they have found that both retailers' and manufacturers' inventories could be reduced while improving service. They did not consider cases with limited manufacturing capacity and issues related to allocating inventory across retailers.

Vendor-managed inventory (VMI) is one of the most widely discussed partnering initiatives for improving multi-firm supply chain efficiency. Waller et al. [WJD99] introduced a simulation model that examines VMI quantitatively in order to understand the effect of key variables. Bhaskaran [Bha98] performed an analysis of supply chain instability for an automobile industry. In this study, it is shown how supply chains can be analyzed for continuous improvement opportunities using simulation. For building the simulation model, automobile supply chain simulation software originally developed to GM's specifications was used. This supply chain simulation software could be used to study the impact of many production control and material management policies on important measures such as inventory levels, forecast stability, and material shortages.

In supply chain modeling, effort is made to consider the effect of policies on the performance of the supply chain. The effects of policies are tested either analytically or through simulation. In the case of simulation for supply chains, effort involved in building the supply chain simulation model can be reduced to a great extent if the models can be built hierarchically from existing modules. Eliter et al. [ESP98] worked on the concept of Agent Programs. An agent consists of a body of software code that supports a well-defined application programmer interface and a semantic wrapper that contains a wealth of information. As part of the work, the team developed agents for various functions of supply chain management systems. A simulation model of a supply chain application based on agents was built using commercial software such as Microsoft Access and ESRI's MapObject. Swaminathan et al. [SSS98] described a supply chain modeling framework that can be used for constructing supply chain simulation models. They develop software components for representing various types of supply chain agents such as retailers, manufacturers and transporters. The authors divide the set of elements in their supply chain library into two categories: Structural Elements and Control Elements. Structural elements correspond to agents (eg manufacturer agents, transportation agents) and control elements correspond to the control policies.

Bagchi et al. [BBE98] discussed the IBM's Supply Chain Simulator. Supply chain simulation involves the simulation of both inter-facility and intra-facility operations. For example, a supply chain simulation tool may model MRP processes, planning and scheduling, capital acquisition, labour and other resources, transportation policies, stocking policies, etc. Bagchi et al. [BBE98] indicated that the key to the usefulness of a supply chain simulator is the ability to translate the simulation information into costs and financial reports. This is typically achieved through the use of activity base costing models.

Jain et al. [JWC01] observed that the level of details included in the development of a simulation model should be appropriate to the objective of the study. They concluded that inclusion of more detail than necessary can easily lead to too large an effort for the objective at hand and the effort not being approved by the parent organization. As part of the work, the authors developed a high level supply chain simulation model using a general-purpose simulation model. Their justification for using general-purpose simulation software instead of a commercially available supply chain simulation tool was that general-purpose simulation software lets the user select the desired level of abstraction. IBM Supply Chain Simulator is one of the commercially available packages for simulating supply chains.

Díaz and Buxmann [DB03] examined how the benefits of Supply Chain Management, as reported by the literature and widely accepted, can simulatively be proven. They presented selected results of a survey conducted on the European automotive industry, which show an evident needed for transparency, in terms of the quantification of the added-value of Supply Chain Management. For this purpose an XML-based prototype for modeling and simulating cooperative scenarios in supply chains is introduced, and illustrated its flexible architecture and the interaction between modeled scenarios and optimization routines through XML (Extensible Markup Language) interfaces. In the context of this prototype the authors describe a simulation scenario in which the transportation activities in a supply chain are modeled and planned.

Chu [Chu03] provided a comprehensive listing of simulation studies to summarize their findings and to identify future research. He classified the simulation studies on supply chains based on its major focus. Referring to his classification and suggestions for future research, the developed simulation model in this thesis can be classified as being a new simulation study to an industry, and new enhancement strategies are to be tested and combined.

Schwarz et al. [SJX04] presented a review study on a class of supply chain management problems which is called Integration or Joint transportation-and-Inventory Problem (JTIP). They carried out a survey of 49 contemporary papers on this problem and outlined problems that deserve further research and possible ways to solve them. Based on their suggestion, this thesis considers two of these: Multi-Product JTIP and Multi-Depot JTIP.

Terzi and Cavalieri [TC04] presented a comprehensive review made on more than 80 articles, the main purpose being to ascertain which general objectives simulation is generally called to solve and which paradigms and simulation tools are most suitable. Useful prescriptions, both for practitioners and researchers, on the applicability of simulation to decision-making processes within the supply chain context were also derived.

By providing a systematic quantitative and objective evaluation of the outcomes resulting from different possible planning scenarios, from demand planning to transportation and distribution planning, simulation techniques can make companies more aware of the benefits coming out from integrated and co-operating strategies with their upstream/downstream locations rather than following myopically an antagonistic behavior with them [TC04].

Regarding the above literature, few papers considered the coordination strategies in supply chains using simulation models [Bea98], [TG96]. Therefore, this work represents one of the new applications that uses simulation to model the coordination strategies in the supply chains.

2.3. Goals of the Dissertation

Regarding to the significant and vast literature on the supply chain coordination problems, this dissertation is designed to achieve some goals. These goals are:

- To study the optimization of distribution strategies, which integrate both transportation and inventory decisions, to search for opportunities for optimizing the supply chain performance
- To build a supply chain simulation model using a discrete-event simulation tool for real life problems
- To use multi-item classification approaches for designing uncoordinated distribution strategies
- To develop new shipment consolidation concepts for constructing new coordination distribution strategies
- To develop new criteria for an item classification concept to be used for designing an efficient coordination distribution strategy

- To apply new initiatives and technologies in supply chain coordination
- To conduct more statistical tests for analysing the real life input data
- To interpret the problems resulting from the coordination strategies
- To estimate multi-criteria for evaluating the performance measures of supply chains
- To conclude new findings and to suggest new trends for further work

3. Modeling Coordination Strategies in Supply Chains Using Simulation: A real-Life Case Study

3.1. Introduction

Supply chain management (SCM) is the management of the flow of products/goods, services, and information from a supplier stage to the end-customer stage. It is a complex process because of the level of uncertainty at each stage of the supply chain. The main objective of problem-solving methods in Supply Chain Management is to reduce uncertainties. Sources of uncertainty are, e.g., the forecast horizon, input data, administrative and decision processes, and inherent uncertainties [VBW98].

One major obstacle in creating a seamless supply chain is uncertainty. In order to deal with this issue, managers must identify and understand the causes of uncertainty and know how it affects other activities up and down the supply chain. This helps them to formulate ways to reduce or eliminate it. Currently, tools for understanding uncertainty are limited to traditional mathematical formulas that do not account for variability. However, simulation is one of the best means for analyzing supply chains because of its capability for handling variability. Companies can use simulation to see how effective and costly an innovative inventory system, such as just-in-time, would be in their own environment without having to implement the system physically [SP00].

A supply chain is a network of facilities that performs the functions of procurement of materials, transformation of these materials into intermediate and finished products, and the distribution of these finished products to customers. A typical supply chain may consist of many participants, such as suppliers, manufacturers, distributors, retailers and the end customer. Each participant in the supply chain has his own set of objectives. Due to its inherent complexity, analytical modeling of supply chains becomes difficult. Moreover, a typical supply chain faces uncertainty in many of its activities, for example, in the supply of raw materials from the suppliers. Under such complex and uncertain situations, simulation becomes the best alternative for analysis [Pun02].

In recent years, operation research models have put more emphasis on modeling and analyzing multi-echelon distribution systems. Though SCM is relatively new, the idea of coordination is not. Thomas and Griffin [TG96] presented an extensive review on coordination of two or more stages of a supply chain and models appropriate for modeling the supply chains.

The main drawback of most analytical models is the fact that numerous constraints have to be satisfied before results can be applied in practice. Most models only take a few variables into account, for example, inventory and running out of stock, and ignore other cost, such as, order processing, handling and transportation. Furthermore, these models neglect capacity restrictions [VBB00].

Due to the complexity of integrated problems, most of the models proposed in the literature are static in nature and consider simple logistics distribution network. Therefore, they do not allow more investigations on the coordination of transportation and inventory decisions. Computer simulation is an especially effective tool to help investigate and analyze complex problems. Because it can be applied to operational problems that are too difficult to model and solve analytically [TC04]. Moreover, mathematical models require too many simplifications and assumptions to model coordination strategies in realistic supply chain problems. Discrete event simulation permits complex logistics systems to be modeled more realistically. This thesis therefore reports the findings of a vast investigation into the discrete-event modeling and simulation of alternative designs and distribution strategies for a supply chain of a food industry company.

3.2. Simulation Model Description

General-purpose discrete event simulation software cannot be directly used for simulating supply chains. The simulation modules provided in the software should be combined or modified to represent the activities typical to supply chains [Pun02]. Based on this idea, a simulation tool is constructed. The simulation tool is a discrete event model, developed based on the combining of the event-scheduling and activity-scanning approaches [BCN03]. The model was created using DOSIMIS-3, with support of a C++ program (DLL). It was developed specifically for the supply chain simulation purpose. Some other tools were customized for the use with this particular model. The database tools used in this model interface readily with widely available application programs, such as Microsoft Excel, Access and Visual Basic for Applications (VBA), to assist in scrutinizing the data.

DOSIMIS-3 is a discrete event simulation tool developed by SimulationsDienstleistungsZentrum GmbH. It is an interactive using objects and graphical working with Windows 95/98/NT/XP. The package is modular-oriented. The simulator works event-discrete and allows simulation of time-discrete material flow systems. A simulated production process can be developed graphically on the screen with no special knowledge in the area of computing necessary. Standard elements, such as sources, sinks, work stations, storages, vehicles etc., which in their structure represent essential modules from the logistics field, allow a rational layout by means of a menu-controlled user interface. Modules with several entrances and exits deploy an intelligence over which local strategies, such as FIFO, minimal occupation of the succeeding module etc. can be realized when controlling the object flow. Thanks to the modular concept there are theoretically no limitations to the scope and size of the simulation. Super-ordinated levels enable the planner to define failures and breaks or to simulate the deployment of workers in any number of freely-definable work sections [GK01], [BKS99].

The simulation tool is controlled by the Dynamic Link Library (DLL) called as location controller programmed by visual C++ program under the DOSIMIS-3 simulation platform. The interaction between DOSIMIS-3, DLL, and other tools is presented in Figure 3.1.

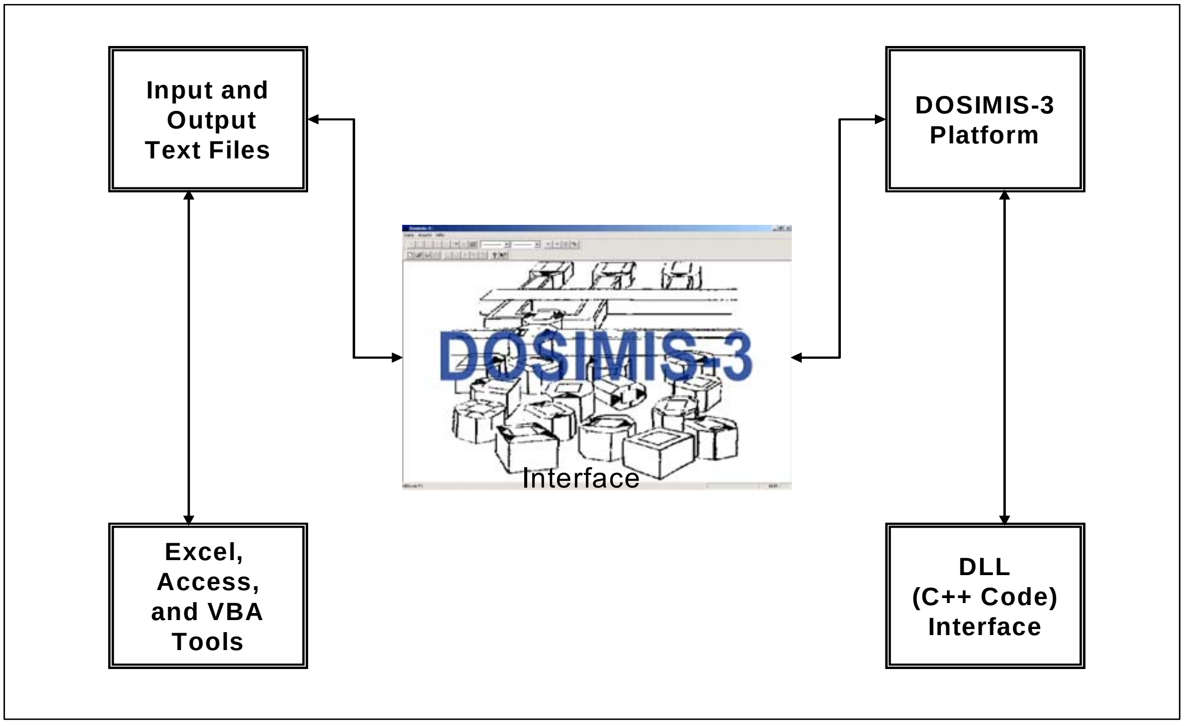

Figure 3. 1 DOSIMIS-3, DLL and Other Tools Interaction

The simulation tool consists of the basic supply chain distribution network elements representing all the locations, items (materials and resources), inventories, and customers in the network. The user enters or imports data about the supply chain distribution network, and the simulation tool predicts the performance of the proposed network, operationally and financially. If the existing network is entered in, alternative scenarios can be tried, in order to see how the existing operation would function if, for example, demand falls, rises or spikes seasonally, for one product, several products, or entire product classes.

The simulation tool also allows the user try out changes to the existing distribution network configuration, to see what the impact would be. Thus, users can evaluate what the effect on the financial status of a previous scenario would have been on if they had implemented centralization via decentralization, or transshipment points via tradition centre distribution.

The following network data is needed to implement the simulation tool:

- **Network Structure:**
  - Items - weight, volume, source.
  - Location - type, name, number.
  - Customer Order (Demand) – date, type and location.

- **Network Policies and Strategies:**
  - Inventory Policy – determine if (at all) the inventory is stocked or not, how often is it counted, when is it replenished, carrying costs,
  - Replenishment Policy – determine the replenishment order size and based on what concept (Only Demanded Order replenishment, others),
  - Sourcing Strategy – determine the source (location) of satisfaction of the customer order (order type, location, item type and number).
  - Transportation Strategy – determine how are shipments transported (Less than Truck Load (LTL), Full Truck Load (FTL) and how much do shipments cost.

- **Production:**
  - Productions are modelled using the black box: simple production lead time and quantities.

- The plants have an unlimited capacity to supply any item or product.

3.2.1. Model Elements

The simulation tool is a system of elements and processes that together control and creates a dynamic system. Bagchi et al. [BBE98] discussed the IBM's Supply Chain Simulator. Supply chain simulation involves the simulation of both inter-facility and intra-facility operations. For example, a supply chain simulation tool may model MRP (Material Requirement Planning) processes, planning and scheduling, capital acquisition, resources, transportation policies, stocking policies, etc. The model consists of the basic elements representing all the activities and processes that are performed in each location, items, inventories, retailers and customer's allocation and shipments in the network. Table 3.1 represents the main location controller DLL classes.

Table 3. 1 Main Location Controller DLL Classes

Class Name	Purpose
ABC Items Class	Determining the class type per item
Items Information Class	Reading the items specification
Make Order Class	Checking the type of orders and flows
Truck Capacity Class	Checking the utilized truck capacity
Spedition Type Class	Determining the shipping order region
Spedition (Shipping Cost) Class	Determining the shipping costs
Customers Class	Reading the customers allocation
Inventory Location Class	Checking type of location (central warehouse, distribution centers, transhipment point, special retailer)
Inventory Control Management Model Class	Appling inventory policy , tracing inventory status, and determining the

	ending inventory
Direct Shipment Class	Checking the possibility of supplying the shipment directly from upper stream location
Tour Management Model Class	Constructing the tour between two points (no routing)
Transportation Type and List Class	Tracing the transportation activities
Activity- Based Cost Class	Estimating the activity-based costs at a location
Main Location Controller DLL	General event control
General Simulation Model Class	General simulation model controller

3.2.1.1. Locations

The model simulates the current network of central warehouses, distribution centres, transshipment points, and special retailers that respond to consumer demand for finished goods SKUs. Suppliers are not considered.

3.2.1.2. Materials and Inventories

Each plant produces a range of finished goods – SKUs – that are produced from a single brand and send them to central warehouses directly. Inventories at distribution centres consist of SKUs. Raw materials are not specifically modelled in this tool. They are not included because they have never been a real constraint to the production plants [SPC03].

3.2.1.3. Transportation Methodology

Several approaches to modelling shipments were considered, but each approach is decided according to a delay time associated with moving material from one location to another (dock to dock). This delay time is assumed to be uniformly distributed between (1 to 4 working days). This is a valid assumption because transportation is not a constraint in this model**.** The delay time from each origin to every possible destination in the model can be entered as an input parameter in DOSIMIS-3 mask parameter.

3.2.1.4. DOSIMIS-3 Elements

To build supply chain network simulation models, some elements of DOSIMIS-3 modules are used. Figures 3.2, 3.3, and 3.4 show the general elements of DOSIMIS-3 modules for building supply chain network models.

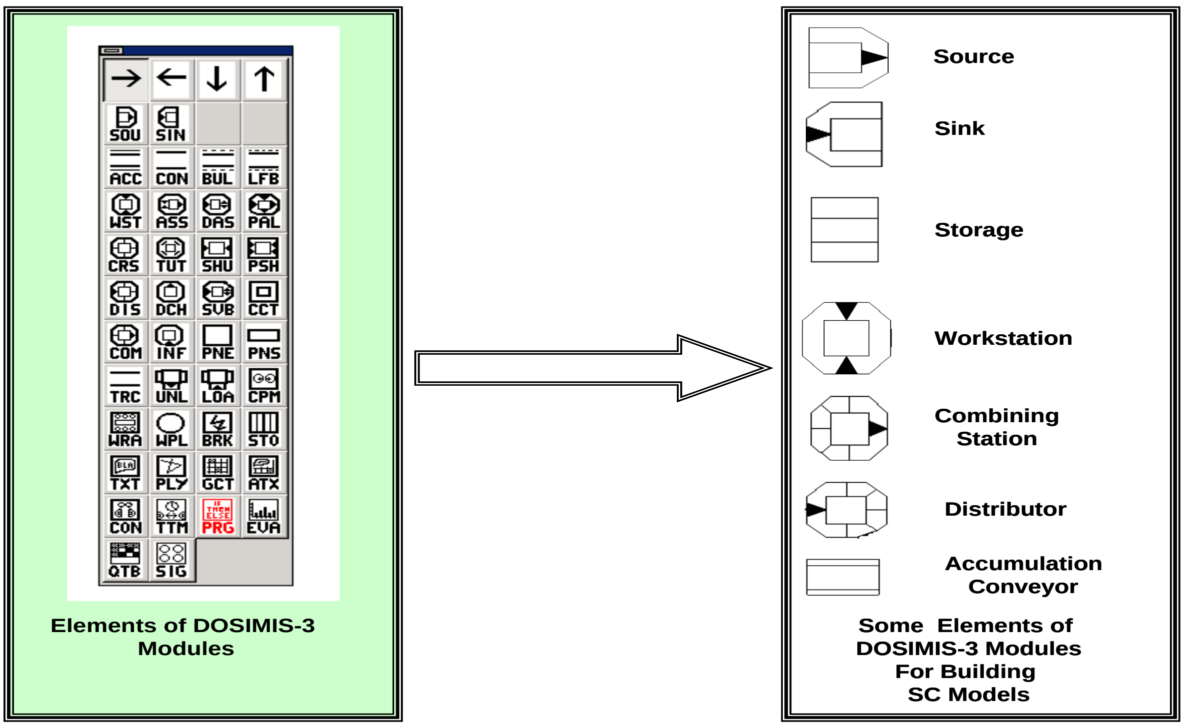

Figure 3. 2 Elements of DOSIMIS-3 Modules for Building Supply Chain Simulation Model

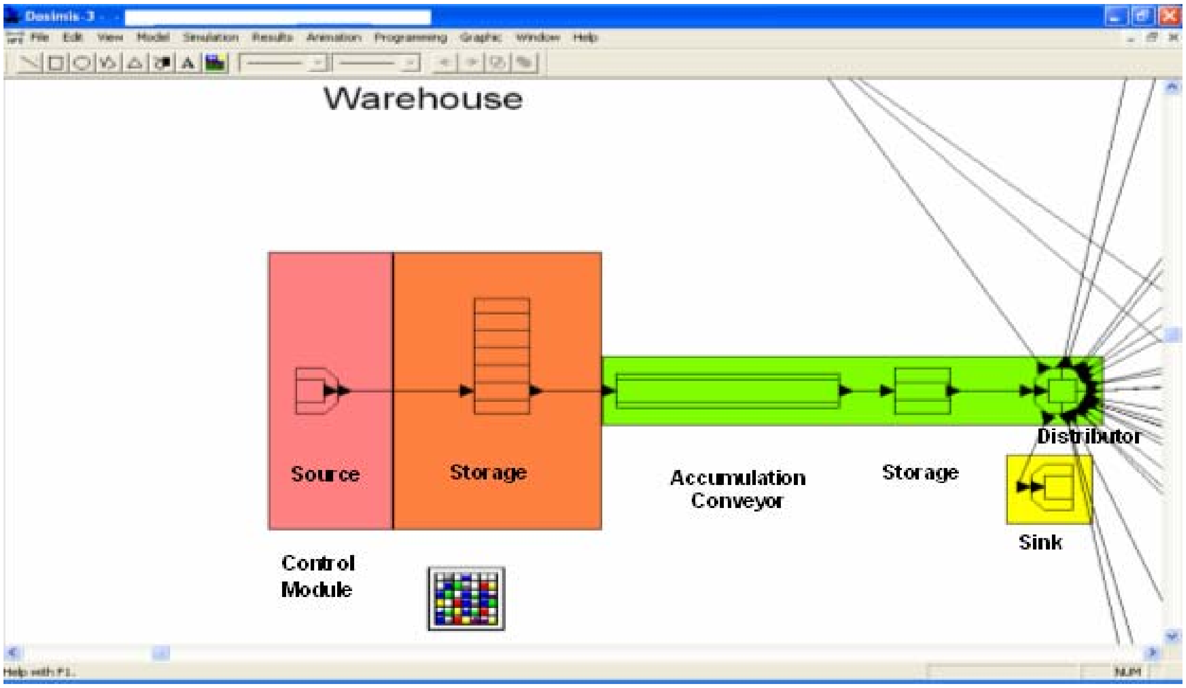

Figure 3. 3 Elements of DOSIMIS-3 Modules for Building Warehouse Location

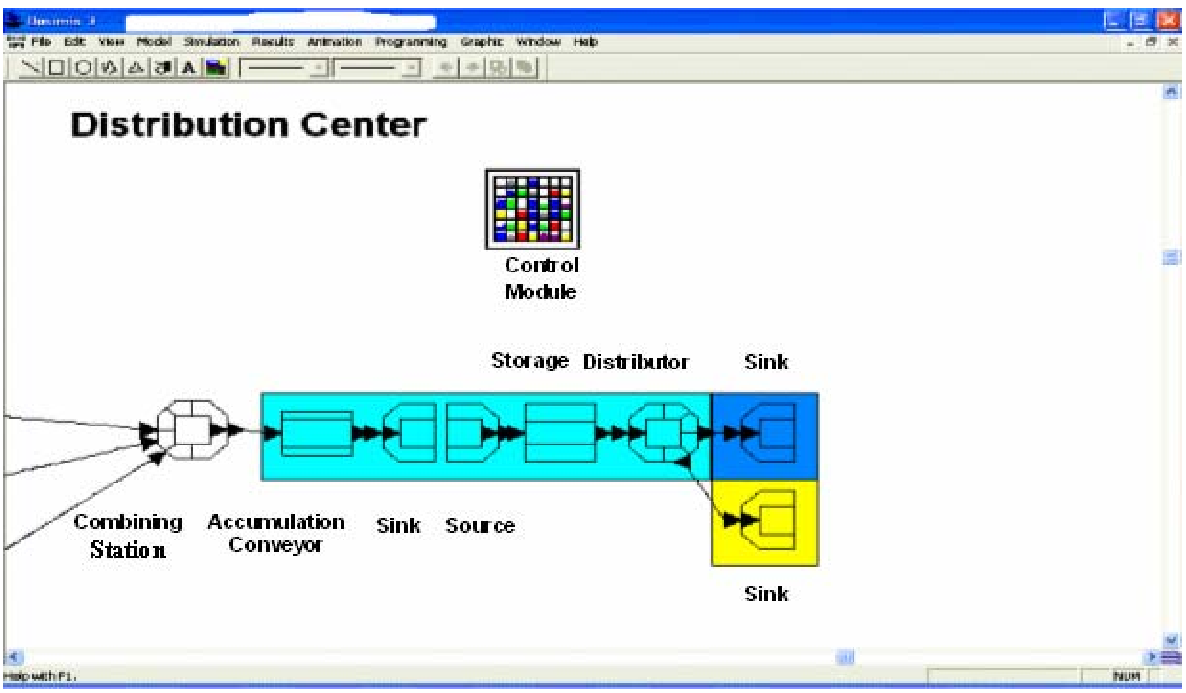

Figure 3. 4 Elements of DOSIMIS-3 Modules for Building Distribution Center Location

The figures show some modules which could be used to represent some processes or functions in the supply chain network. Constructing these modules depends on the location and the process needed at that location in the network. For example, at both locations (warehouse and distribution centre), the sending of shipments process is needed and presented by the distributor module. Also, the storing of materials process is needed and presented by the storage module.

3.2.2. Model Data

Using a simulation tool that has been specifically designed for supply chain analysis allows users to build models of their supply chains, to investigate different operating strategies and to improve the efficiency of their models. In order to use the simulation tool it must be supplied with the required information. Information should be given to the simulation tool to define the required input data for each location type in the supply chain model. The required input data is entered in two ways; using external files or using the Mask Parameters of DOSIMS-3 modules.

3.2.2.1. Input Data in External Files

External files which can be read by the simulation tool are generated. These files are text files and provide information on the following areas at each location:

- **Central Warehouse Location:**

1. File Group 1: "customer xxx.txt" This file contains information on location and customer data. Table 3.2 shows one part of a customer file for one warehouse.

Table 3. 2 Customer File of one Warehouse Location

Warehouse-Nr	Customer-Nr	Name	Location	ZIP *	Distance (Km)
1	4723	Customer A	Duisburg	47119	85
1	5128	Customer B	Augsburg	86161	552
1	8852	Customer C	ESSEN	45144	67

***** ZIP: ZIP code or Postal Code

2. File Group 2:"Production xxx.txt" This file provides general information on the production. Table 3.3 presents the content of one file of file Group 2.

Table 3. 3 Production File of one Warehouse Location

Starting Date and Time	Order-Nr	Material	Quantity	Plant
DD.MM.YY 06:00	2053	A9291	1278	1
DD.MM.YY 06:00	3158	A9295	2880	1
DD.MM.YY 06:00	4578	A7297	3440	1

3. File Group 3: "Item xxx.txt " This file gives specific information on items (weight, volume, name, and number) and items loading units. Table 3.4 exhibits a list of this file.

Table 3. 4 Item File of Whole System

Material	Material Name	Plant-Nr	Weight per Bag	Quantity per Carton	Volume of Carton	Quantity per Pallet	Pallet Height
A9978	AXYZ	3	0.115	20	0.0408	640	2190

4. File Group 4:"activity-based cost xxx.txt " This file provides information on the activity costs like loading, unloading, picking, preparing of order and

consolidating of shipments activities. Table 3.5 presents the content of one file of this group.

Table 3. 5 Activity- based Cost File of one Warehouse Location

Activity	Cost	Description
Order Preparing	1.2	$ per Order
Order Pecking	0.10	$ per carton
Unloading	0.60	$ per Pallet
loading	0.40	$ per Pallet
Consolidating	0.20	$ per carton

5. File Group 5:"freight cost xxx.txt " This file provides information on the freight rate and cost structure (Transportation Matrix). For example transport rate discount and cost rate of each region. Also it provides information on the capacity of the truck. Table 3.6 shows a part of transportation matrix for one warehouse location.

Table 3. 6 Freight Cost File of one Warehouse Location

Warehouse-Nr	Pal min	Pal max	Destination	ZIP min	ZIP max	Freight Price	Per	Spedition
1	1	1	5240	00000	09999	20	PAL	C
1	1	1	6234	10000	19999	21	PAL	C
1	1	1	1268	20000	29999	22	PAL	C
1	1	1	8742	30000	39999	25	PAL	B
1	1	1	5489	40000	49999	24	PAL	B
1	2	2	5240	00000	09999	17	PAL	C
1	2	2	6234	10000	19999	18	PAL	C
1	2	2	1268	20000	29999	19	PAL	C
1	2	2	8742	30000	39999	22	PAL	B
1	2	2	5489	40000	49999	21	PAL	B

- **Distribution Centre Location:**
  1) File Group 1: "inventory management xxx.txt " This file contains information on location number, item number, initial, minimum, and maximum inventory, and interval period of keeping the inventory. Table 3.7 illustrates one part of an inventory management file for one distribution centre.

Table 3. 7 Management Inventory File of one Distribution Center

DC-Nr	Item - Nr	Initial Inventory	Min-Inventory	Max-Inventory	Inventory-from	Inventory-to
12	A9874	78401	78401	196002	DD.MM.YY	DD.MM.YY
12	B7458	27631	27631	69078	DD.MM.YY	DD.MM.YY
12	D4125	23910	23910	59774	DD.MM.YY	DD.MM.YY
12	A6548	10031	10031	25077	DD.MM.YY	DD.MM.YY

  2) File Group 2: "demand xxx.txt" This file contains detailed information on the order customer. Table 3.8 presents the content of one part of file Group 2 for one distribution centre.

Table 3. 8 Demand (Order Customer) File of one Distribution Center

Date	Order-Nr	Item - Nr	Quantity	Customer-Nr	DC-Nr	Warehouse-Nr	Number of Units per Pallet
DD.MM.YY	1245	A9486	16320	8475	15	3	4809
DD.MM.YY	4123	C5987	1252	1844	15	1	1445
DD.MM.YY	4591	D8743	51230	8795	15	1	6407
DD.MM.YY	5481	A4578	480	2541	15	3	6402
DD.MM.YY	5525	B9852	1000	1259	15	3	6408
DD.MM.YY	5932	B5669	2258	7895	15	1	6409
DD.MM.YY	6548	C6603	550	4823	15	3	6405

3) File Group 3: "ABC xxx.txt " This file contains information on classification of the items. Table 3.9 presents the content of one part of file Group 3 for one distribution centre.

Table 3. 9 ABC File of one Distribution Centre

Item	Quantity	Cum. Quantity	Class
A8956	12289	12289	A
C8986	11172	23461	A
C9840	10258	33719	A
D5735	9856	43575	A
B6739	8229	51804	A

4) Other File Groups: The other file groups provide the same information provided by some of the file groups at the central warehouse location. These Files are:

    a. “customer xxx.txt ", as shown in Table 3.2.
    b. "item xxx.txt ", as shown in Table 3.4.
    c. "activity- based cost xxx.txt ", as shown in Table 3.5.
    d. "freight cost xxx.txt", as shown in Table 3.6.

3.2.2.2. Input Data in Mask Parameters

The other required information is entered through the Mask Parameters of DOSIMS-3 modules. Two mask parameters interfaces are designed specifically for supply chain models by DLL (C++ code) under DOSIMIS-3 platform. These mask interfaces are system control mask parameters and global mask parameters. Figure 3.5 shows both masks. The input data for these masks are:

The input data to the system control are:

- Location information: number, name, and type
- Item-Inventory information: items list, reorder point, maximum, minimum, and initial stocking quantities, and customer allocation.
- Flow information: production, order flow in terms of customers demand.
- Cost information: activity- based and freight costs per location.
- Inventory policy: Allowed to keep inventory (Traditional Store) or not allowed (Transhipment point)
- Item Class: ABC classification.
- Replenishment Policy – (Only Demanded Order policy, others),
- The global system parameter asks for the dimensions of the mixed pallets and the standard pallets like height, maximum number of pallets that can be stacking on top of each other and the working days calendar (Figure3.5).

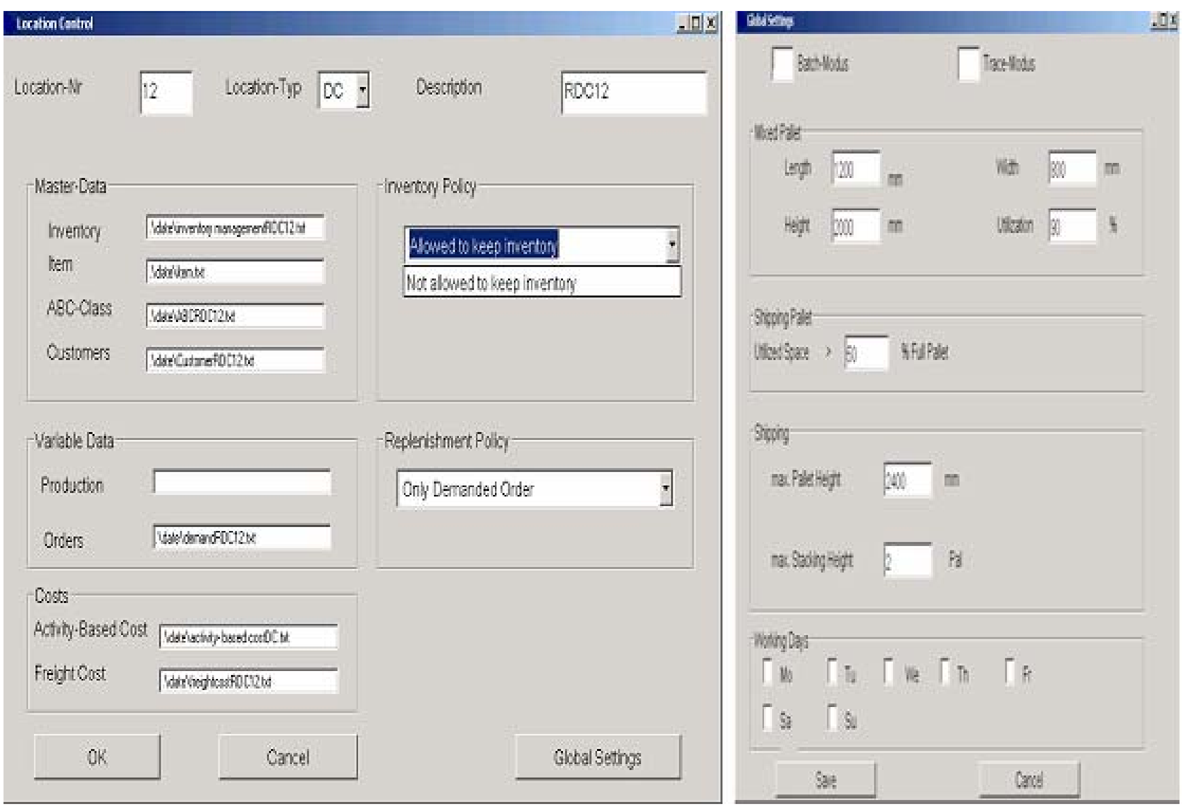

Figure 3. 5 Simulation Model Input Data Parameter Masks

3.2.3. Model Output Reports

The key to the usefulness of a supply chain simulator is the ability to translate the simulation information into costs and financial reports [BBE98]. This is typically achieved through the use of activity-based costing models. Therefore, the developed simulation model generates more detailed information about the activity-based costs by each location in the network. Once the model has been simulated, the user can get detailed statistics on almost every aspect of the model's performance. The data from the simulation has been summarized in a number of different ways to provide information in the following areas:

- Service Level (Fill rate)
- Transportation
- Inventory
- Activity -based Costs

Some of the standard output reports produced by the model include: financial summary reports, inventory levels, transportation rate/levels, and service order degree reports.

3.2.3.1. Financial Summary Report

- Network total cost.
- Detailed network wide expenses, including transportation costs, inventory carrying costs and activity- based costs.
- Detailed financial split out by site (for all articles): warehousing, inventory, transportation costs (Table 3.10).

Table 3.10 Activity-Based Cost File of a Distribution Centre

Date and Time	Action	Item - Nr	From	To	Sum-Pal	Pal-Typ	Sum-Carton	Pickup-Carton/Pal	Costs
DD.MM.YY 16:00	Ordering	-	18	5555	0		0	0	1.2
DD.MM.YY 16:00	Picking	A7072	18	5555	1	EP	2	2	0.20
DD.MM.YY 16:00	Picking	B8033	18	5555	1	EP	5	5	0.50
DD.MM.YY 16:00	Picking	B9134	18	5555	1	EP	5	5	0.50
DD.MM.YY 16:00	Picking	A7738	18	5555	1	EP	10	10	1.00
DD.MM.YY 16:00	Picking	C7539	18	5555	1	EP	20	20	2.00
DD.MM.YY 16:00	Picking	C8855	18	5555	1	EP	5	5	0.50
DD.MM.YY 16:00	Picking	D8077	18	5555	1	EP	2	2	0.20

EP: Standard European Pallet

In the above table, the cost per event time for each activity required for one order per customer is calculated.

3.2.3.2. Inventory Levels

Some reports for tracing inventory are created:

- Detailed tables of inventory status by item, by location, for the entire network, for the entire run (Table 3.11).
- Aggregated inventory investment, by location, and for the entire network, for the entire model run (Table 3.12).

Table 3.11 Inventory Tracing File of a Distribution Center

Date and Time	Action	Item -Nr	Q	Stock	Min	Max	Res-Q	Back-Order	In-Transit	Dlv-Q.
DD.MM.YY 12:00	RES	A9272	120	1549	1549	3874	120	0	0	0
DD.MM.YY 12:00	RES	C5833	500	5373	5373	8955	500	0	0	0
DD.MM.YY 12:00	RES	C9834	250	5364	5364	13410	250	0	0	0
DD.MM.YY 12:00	RES	B7738	188	12356	12356	30890	188	0	0	0
DD.MM.YY 12:00	RES	B8939	228	5862	5862	14655	228	0	0	0
DD.MM.YY 12:00	RES	D6655	700	3432	3432	5720	700	0	0	0
DD.MM.YY 12:00	RES	D6677	260	2583	2583	3874	260	0	0	0

Q: quantity

RES: reservation action.

Res-Q: reserved quantity.

Dlv-Q.: delivered quantity.

In the above table, all inventory actions per event time required for each item are traceable. The status inventories (stock levels) per event time for each item are also traceable. This table provides information on the backorder, in-transit, and delivered quantities for each item.

Table 3.12 Aggregated Ending Inventory File of a Distribution Centre

DC	Date and Time	Ending-Inventory (Pallet)
14	DD.MM.YY 16:00	2586
14	DD.MM.YY 16:00	3224
14	DD.MM.YY 16:00	1258
14	DD.MM.YY 16:00	1169

From the above table, the daily ending inventory and average ending inventory for one year could be calculated.

3.2.3.3. Transportation Rates/ Levels

For the computation of the transportation costs, a detailed and complex transport cost matrix has been considered for the calculation based on different calculation criteria. Some of output files regarding transportation are explained:

- Aggregated toll transportation fees, by location, for the entire network, and for the entire model run.
- The flow of shipments and the shipment quantity between the locations and their destinations, for the entire network, and for the entire model run (Table 3.13).
- The transportation frequencies and utilized truck capacity between central warehouses and distribution centres per location (Table 3.13).
- Tour plan and tour trace by location, for the entire network, and for the entire model run (Table 3.14 and 3.15).

Table 3.13 Shipment Flow File of one Distribution Centre

DC	Date and Time	Action	Tour Nr	From	To	Nr-Pallet
17	DD.MM.YY 16:00	Shipping	T 1	17	4217	6
17	DD.MM.YY 16:00	Shipping	T 2	17	3642	9
17	DD.MM.YY 16:00	Shipping	T 3	17	3372	20
17	DD.MM.YY 16:00	Shipping	T 4	17	3356	15
17	DD.MM.YY 16:00	Shipping	T 5	17	2613	30
17	DD.MM.YY 16:00	Shipping	T 6	17	1817	4
17	DD.MM.YY 16:00	Shipping	T 7	17	1496	8

Table 3.14 Tour Plan File of one Distribution Center

Date and Time	Tour Nr	From	To	Pal	Weight	Freight Price/Pal	Cost
DD.MM.YY 16:00	T 1	17	4217	6	315	20 P	120
DD.MM.YY 16:00	T 2	17	3642	9	722	18 P	162
DD.MM.YY 16:00	T 3	17	3372	20	856	10 P	200
DD.MM.YY 16:00	T 4	17	3356	15	802	12 P	180
DD.MM.YY 16:00	T 5	17	2613	30	978	7 P	210
DD.MM.YY 16:00	T 6	17	1817	4	258	22 P	88
DD.MM.YY 16:00	T 7	17	1496	8	654	18 P	144

Table 3. 15 Tour Trace File of one Distribution Center

Date and Time	Action	Item-Nr	From	To	Pal	Pal-Typ	Quantity	Weight
DD.MM.YY 16:00	LOAD	A6132	17	4217	0,04	EP	20	3.78
DD.MM.YY 16:00	LOAD	B8033	17	4217	0,05	EP	30	5.67
DD.MM.YY 16:00	LOAD	B6934	17	4217	0,05	EP	30	5.55
DD.MM.YY 16:00	LOAD	D8838	17	4217	0,06	EP	30	6.6
DD.MM.YY 16:00	LOAD	C7546	17	4217	0,04	EP	20	3.78
DD.MM.YY 16:00	LOAD	C9755	17	4217	0,02	EP	10	2.10
DD.MM.YY 16:00	LOAD	B4556	17	4217	0,02	EP	10	2.10
DD.MM.YY 16:00	LOAD	C5562	17	4217	0,02	EP	10	2.10
DD.MM.YY 16:00	LOAD	A6677	17	4217	0,02	EP	12	2.26

3.2.3.4. Service Order Degree Reports

The simulation model generates detailed reports for analysis of the satisfaction of customer orders by location, for the entire network, and for the entire model run (Table 3.16).

Table 3. 16 Service Order Degree File of a Distribution Center

Start Date and Time	Order-Nr	Customer-Nr	End Date and Time	Duration Time	Effective Duration Time
DD.MM.YY 12:00	2053	3651	DD.MM.YY 16:00	0 04:00	0 04:00
DD.MM.YY 12:00	3329	9874	DD.MM.YY 16:00	0 04:00	0 04:00
DD.MM.YY 12:00	9682	6947	DD.MM.YY 16:00	0 04:00	0 04:00
DD.MM.YY 12:00	7295	8569	DD.MM.YY 16:00	0 04:00	0 04:00
DD.MM.YY 12:00	3654	5726	DD.MM.YY 16:00	0 04:00	0 04:00
DD.MM.YY 12:00	7621	7123	DD.MM.YY 16:00	0 04:00	0 04:00

Table 3.16 gives information on the interval period of time between receiving an order from a customer to delivering the order (duration time). From this information, the delay time in delivering the orders of customers could be estimated. Effective duration time is the duration time minus the allowed delay time (week end time).

3.3. Model Policies and Strategies

Some inventory policies and transportation strategies are modeled and implemented by the simulation model. These policies and strategies will be described in the following section.

3.3.1. Inventory Management Policies

In this simulation model, the location inventory in the supply chain network uses the continuous review installation stock (**s,S**) policy where ***s*** is the reorder point and ***S*** is the order up-to-level. The stocks are controlled in a decentralized manner by installation stock reorder points [Axs00]. The simulation model checks continuously whether the customer orders have reduced the net current inventory position of any item at each location to a level less than the reorder point ($\mathbf{s_i}$). When the net current inventory position falls below the reorder point, the inventory system will make a replenishment order from the inventory of its upstream location. The process continues until enough material has been received at the location to fill all current orders. Net current inventory position is a number calculated throughout the simulation. The formulas (3.1), (3.2) and (3.3) give expression of the replenishment (order) quantity.

However, if the stock on-hand cannot fill the order, the order will be held in a queue in the inventory system; this means the order becomes a backorder. The backorders are held in a queue in the location. The backorder queue is implemented as a first-in-first-out (FIFO) queue. Whenever the on-hand, on-order, and backlog are updated, the net current inventory position *(inventory on-hand + on-order - backorders)* will be updated. The inventory system can fill the backorders only when the replenishment orders (shipments) arrive. There is a time delay for the shipments to arrive (lead time).

Inventory Tracking files keep track of the possible status of an existing orders that are open or delivered, and the inventory status include received, in-process, in-transit, or delivered.

The values of initial inventory on hand, minimum order quantity ($\mathbf{s_i}$), the maximum inventory level ($\mathbf{S_i}$) and the allowed interval time to stocking for each item type can be obtained from the *Inventory Management files* (Table 3.7) as input parameters.

$$I(t)_i = H(t)_i - B(t-1)_i + O(t-1)_i \tag{3.1}$$

$$H(t)_i = AIV(t)_i - \sum_{n=1}^{N} RESV(t)_{ni} \tag{3.2}$$

If $I(t)_i \leq s_i$

$$Q_i = S_i - I(t)_i \tag{3.3}$$

Else,

$Q_i = 0$

Where

$I(t)_i =$ inventory position level at time t for item type i.

$H(t)_i =$ inventory on hand at time t for item type i.

$B(t-1)_i =$ back-order quantity at time $t-1$ for item type i.

$O(t-1)_i =$ on-order quantity at time $t-1$ for item type i.

$AIV(t)_i =$ actual inventory level at time t for item type i.

$RESV(t)_{ni} =$ reserved customer order quantity of customer order n at time t for item type i.

$Q_i =$ replenishment quantity for item type i.

$s_i =$ reorder point for item type i.

$S_i =$ order-up-to-level for item type i.

$N =$ total number of reserved orders.

Notes:

- The order size is rounds up to make full pallet per item type and the minimum value of the replenishment quantity is one pallet ($Q_i = 1$).
- The customer orders are filled completely or partially (some of available items).
- The filling of customer orders is based on a first-in-first-out (FIFO) rule.

The inventory policy in the previous page is used when the location has been selected as the “distribution center” for location type and with “Allowed to keep inventory” as inventory policy. In this case all the inventory decisions are taken at this location (DC).

3.3.2. Transportation Strategies

In this model all items are placed on pallets for shipment. Trucks are used to carry the shipments. Direct shipment between locations is considered and no routing decisions have been taken. Two common shipping strategies have been modelled. These two strategies are the Full Truckload (FTL) and Less-than-Truckload (LTL). The planner can select one of them through the appropriate selection of the replenishment policy.

3.3.2.1. The Units of Transportation

In the traditional transportation problem, the main issue is the cost pattern of shipment, and the form or the unit of transportation is not taken into consideration. In the actual transportation, however, the form or the unit of transportation is one of the most important issues to be considered, because the number of products to be transported at a time depends on the unit of transportation [TF99]. The units of transportation at the four stages of transportation are illustrated in Figure 3.6, as treated in this model. The four stages are; 1) a single item, 2) a box, 3) a pallet, and 4) a truck. A certain number of pieces of the item type are packed in one box. The number of pieces for each item is specified, considering the size of both the item and the box. Then, a certain number of boxes are put on one pallet, which might be handled by a forklift truck. Finally, a specified number of pallets are loaded on one truck; two pallets can be stacked on top of each other. The necessary information about the size, weight, the number of items for one box, and the number of boxes for one pallet should be determined for each item to be transported in the simulation model. In addition, the capacity in terms of the number of pallets to be loaded onto the truck should be decided for each combination of the supply.

All the above information is given in the item files (Table 3.4) and freight cost per location files (Table 3.6). Also, information on the pallet dimensions should be given by the Planner (Figure 3.5).

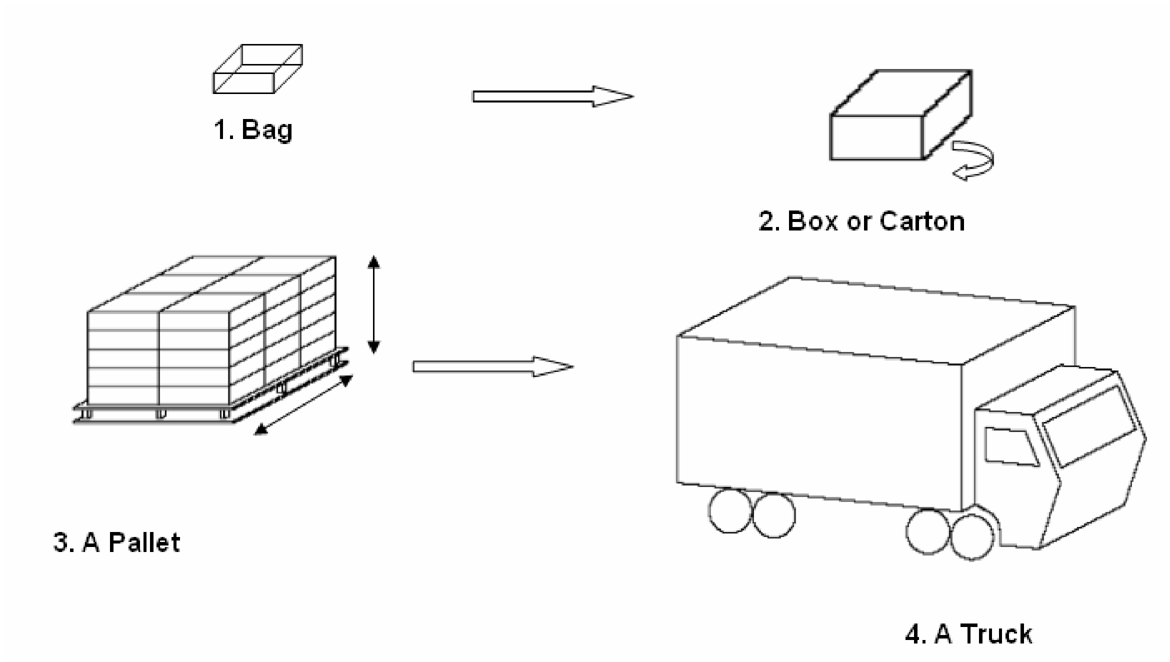

Figure 3. 6 Units of Transportation

3.4. Model Implementation

This section describes an overview of how the simulation model is implemented. The modules make use of the DOSIMIS-3 and DLL (C++ Code) interfaces. The DOSIMIS-3 software interacts with DLL (C++ Code) under the DOSIMIS-3 platform. Each location of the supply chain has text files associated with it. So whenever the DLL is called, depending on the type of location and the activity to be executed, the corresponding text file is accessed and data is read or written using DLL class. Functions and procedures are written in C++ Code to execute the activities in supply chain, such as, consolidation of items for orders, and delivering the shipment.

For building supply chain models using DOSIMIS-3 modules, the modules are put together and connected using their interfaces. So each location in the supply chain network has its own set of modules (Figure 3.2, 3.3, and 3.4). In addition, text files corresponding to each location should also be present. These text files and DOSIMIS-3 modules are linked for each location by DLL under the DOSIMIS-3 platform (Figure 3.5).

DOSIMIS-3 provides a hierarchical modeling. This means that a model can consist of sub-models. The supply chain simulation model consists of sub-models that correspond to the modules in the proposed template. The DLL code with the text files performs planning activities. Execution is carried out under the DOSIMIS-3 environment. Enable processes are modeled as inputs to the simulation either in the form of text file data or parameters in the DOSIMIS-3 model.

DOSIMIS-3 triggers various scheduling events in DLL either at periodic intervals (e.g. checking inventory) or based on random events (e.g. customer placing an order). Some of these types of events are illustrated in Table 3.17.

Table 3. 17 Types of Events Modelled

Event Type	**Event Description**
1	Arrival of a shipment from the Warehouse
2	Place an order from end-customer
3	Update inventory level
4	Starting or Ending Pickup and Consolidation of Orders
5	End of simulation after t years

When DOSIMIS-3 triggers an event, some activities should be achieved by the DLL Code. For example, when the arrival of an order from the end-customer at the distribution center occurs then some activities should be executed to fill the order. The flowchart of order fulfillment control activities at the warehouse and distribution center locations is shown in Figure 3.7.

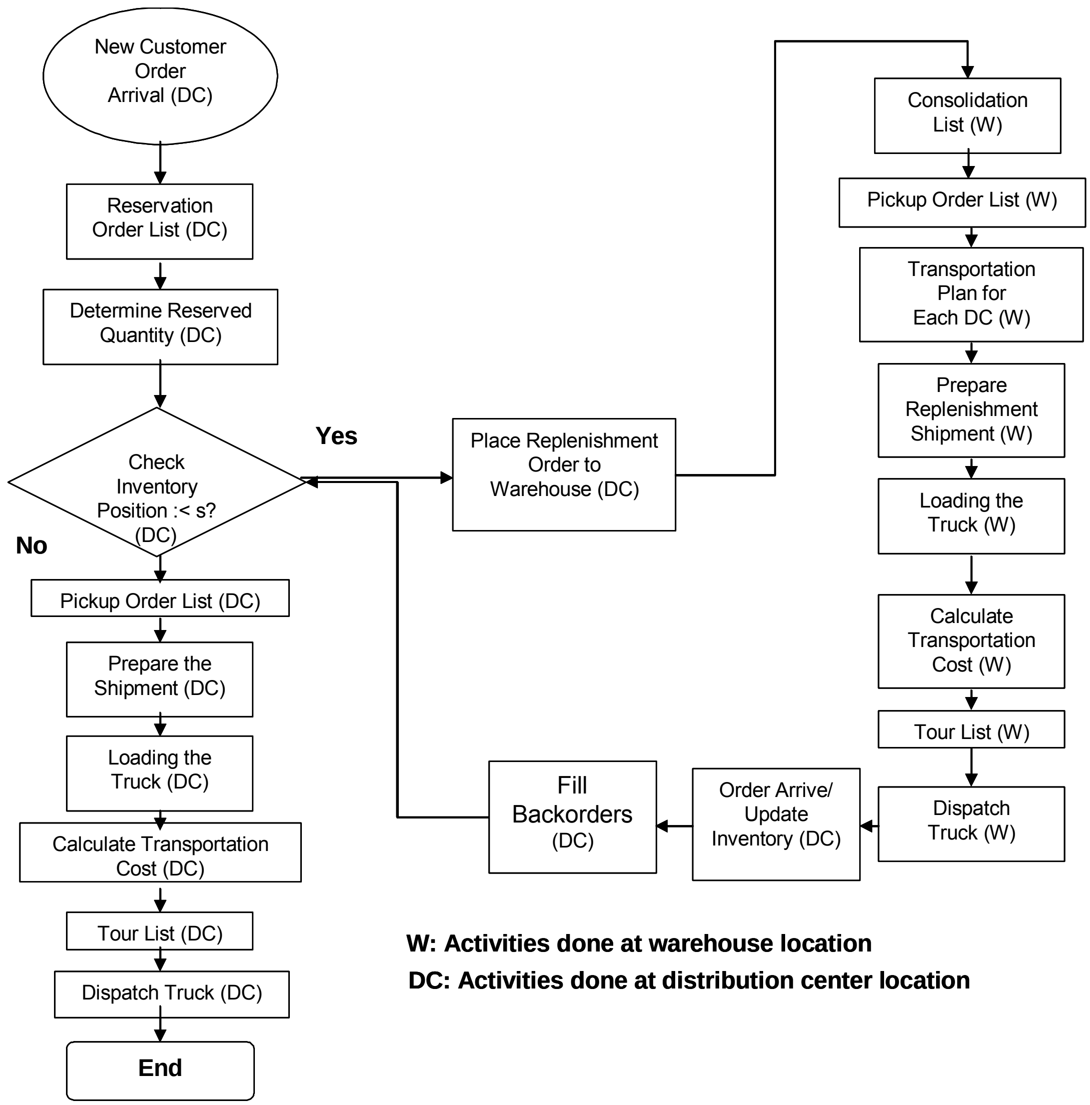

Figure 3. 7 Flowchart of Order Fulfillment Control Activities at Warehouse and Distribution Center Locations.

Every time a planning activity is carried out, the system status is checked and actions are taken depending on the status. Information flow can be of two types. One type of information flow records the status of the system that will be used for calculating the performance measures. The other type of information flow triggers events in the model, this includes planning activities that occur while checking the status of the system and events, such as, placing of an order by the customer. The simulation progresses due to the triggering of such events.

In addition to the rolled up reports from the model itself, detailed reports are created for verification and analysis. The simulation model can write detailed data to text files while the model runs. Collected text files include daily records (such as inventory for each location for each SKU for each day, order point by location and SKU, and backorder by Location and SKU). The other text files (output reports) created for detailed analyses are described the previous sections.

The text files are created for use in an external statistical package such as Microsoft Excel. Through the results of the simulation analysis, users can assess the relative merits of alternative supply chains, as well as predict their impact on costs and delivery.

3.5. Model Optimization

When evaluating a system with many different combinations of possible options, it can be difficult to execute all possible combinations and identify all of the possible trade offs. Although users are able to play "what if" with input data and simulation scenarios to obtain potential solutions, the optimization subsystem helps to eliminate the need for random trial and error.

In this simulation model, ***ad hoc approaches*** that required the user to manually try many sets of input parameters for optimizing are used [SP00].

3.6. A Real-Life Case Study

3.6.1. A Real Distribution Supply Chain Description

A real life distribution supply chain in a food industry has been considered. The company is located in a European country, produces three major brands of products, and holds more than 3000 different SKUs per day (stock keeping unit). Currently, this company has several production locations (plants), central warehouses, about 30 regional distribution centres, and approximately more than 5000 retailers and customers spread over the country. The warehouses are located at the plants and deliver different items to distribution centres which in turn supply a large set of geographically scattered retailers. It is assumed that the warehouses replenish multi-items from infinite supply plants and act merely as coordinators of the supply process, but do not hold any stocks.

The distribution centres hold stocks of multi-items and use common inventory policies to replenish their inventory levels. Each distribution centre faces a dynamic demand rate. Figures 3.8 shows the distribution supply chain network considered with the dynamic of flow orders; and Figure 3.9 shows the locations inside the country.

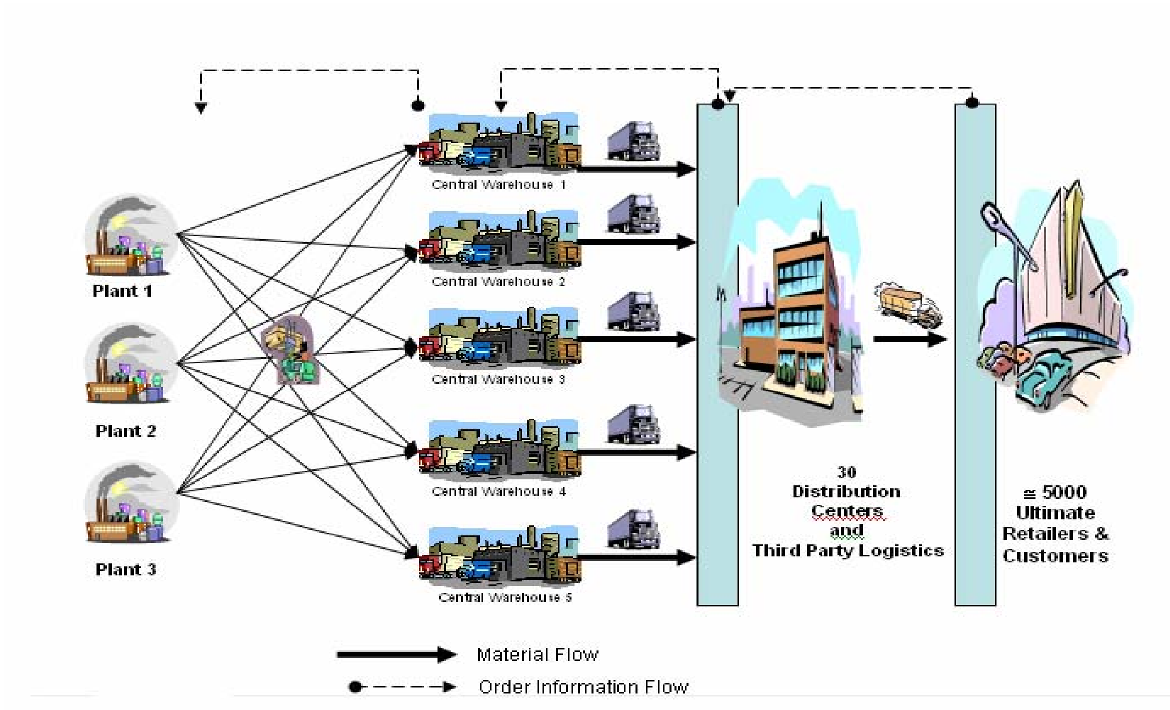

Figure 3. 8 A Real Distribution Supply Chain Network

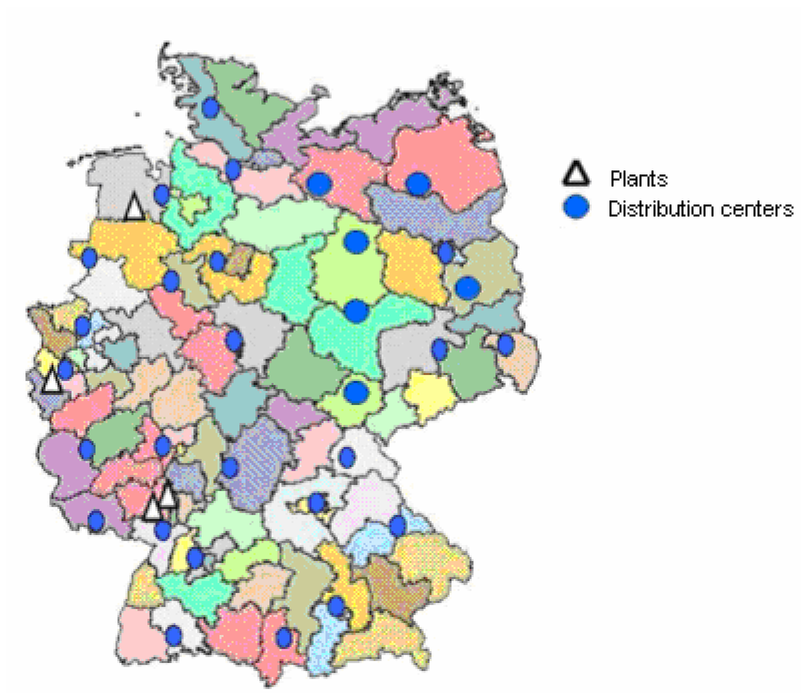

Figure 3. 9 Plants and Distribution Centers Location

The detailed description of the model considered has been presented in the following section:

3.6.2. Model Data and Analysis

A significant amount of historic data from the company's ERP (Enterprise Resource Planning) system has been used to conduct the simulation study. In the first phase of the simulation study, an extensive data analysis was accomplished. In this study only 3 plants, 3 warehouses, and 24 regional distribution centres (RDCs) are included. The distribution centres have different size of customers (small, medium, and large). Five distribution centres with small-sized customers are assumed to operate as local distribution centres (LDCs) and are not responsible for delivering to their customers. The customers receive their orders by an own truck fleet. The 19 regional distribution centres that have medium and large-sized customers are responsible for delivering to their customers.

3.6.2.1. Items (Articles) Data

Different types of items are produced by the plants. In total, the items are produced in 392 different types. The plants' production is enough to meet orders received daily. Figure 3.10 shows the number of different item types for each plant.

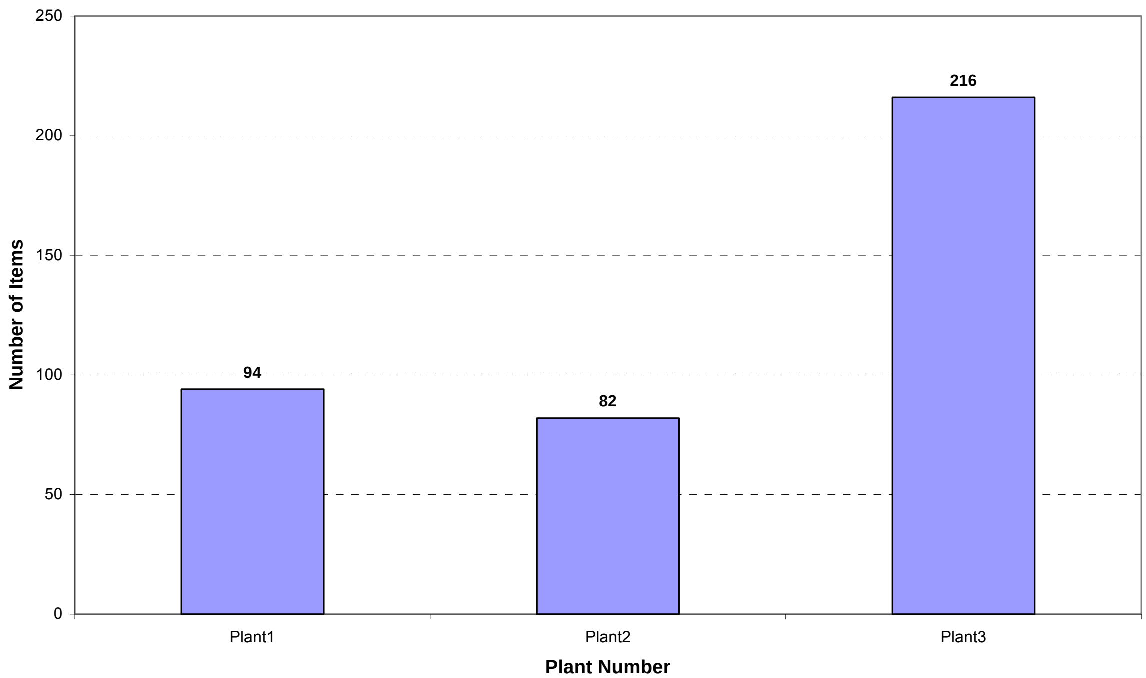

Figure 3. 10 Number of Item Types per Plant

The items have different characteristics (name, weight, and volume). The distribution centres keep stocks of multi-item (SKU) and use the three warehouses to replenish their inventory levels. Each distribution centre holds different types of items. The number and percentage of different item types replenished from each warehouse to each distribution centre is shown in Figure 3.11.

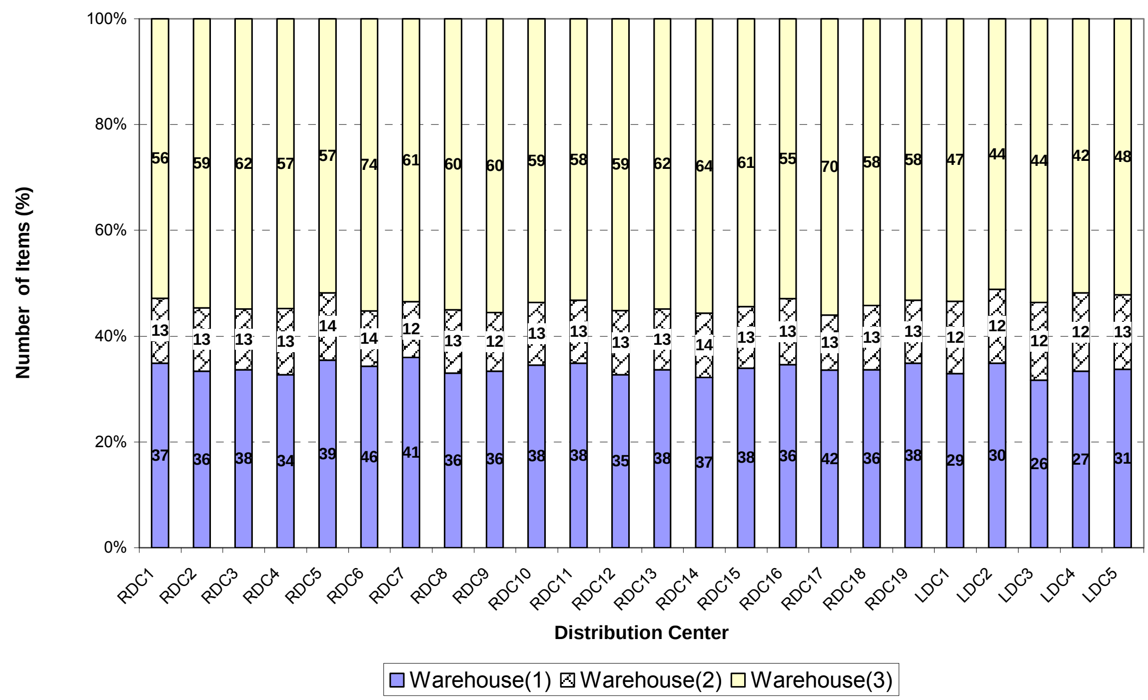

Figure 3. 11 Number and Percentage of Replenished Items from each Warehouse type to each Distribution Center

3.6.2.2. Customer Orders Data and Analysis

The following set of customer information has been considered in the simulation model:

- Customer name
- Customer number
- Address
- Travel Distance from the regional distribution centres
- Type of customer

The customer orders for each distribution centre for one year are also collected from the company and have been analyzed. Each distribution center receives daily orders of different items (order lines) from retailers and customers. Figure 3.12

illustrates the average daily number of order lines per distribution center. The total number of customers and retailers at each distribution center is presented in Figure 3.13.

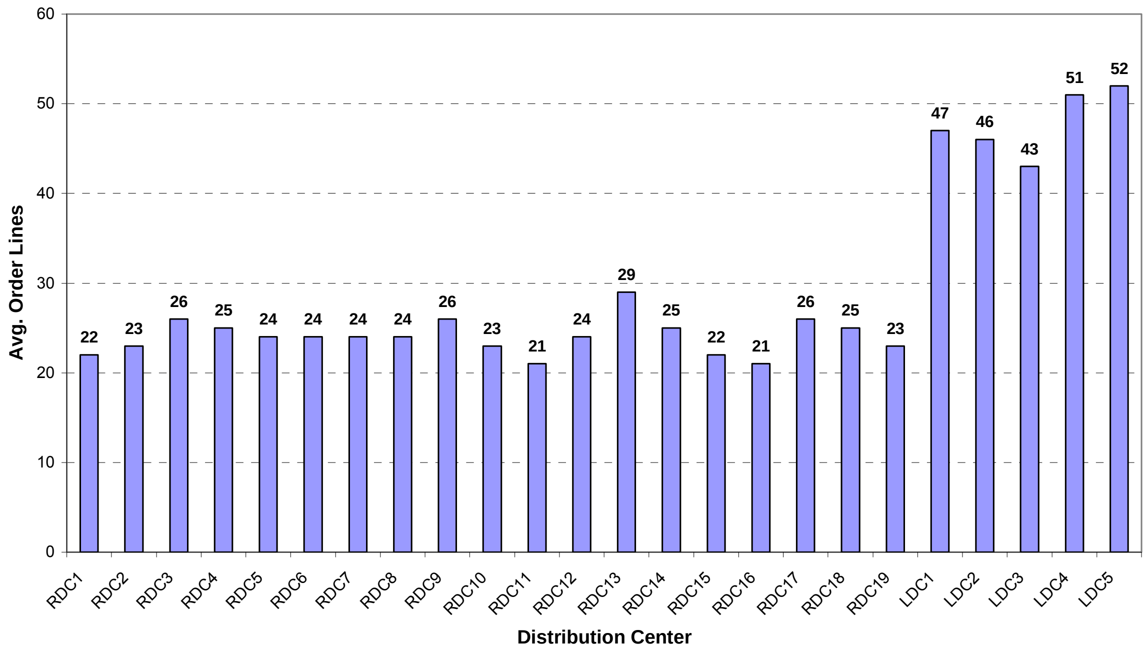

Figure 3. 12 Average Number of Order Lines per Distribution Center

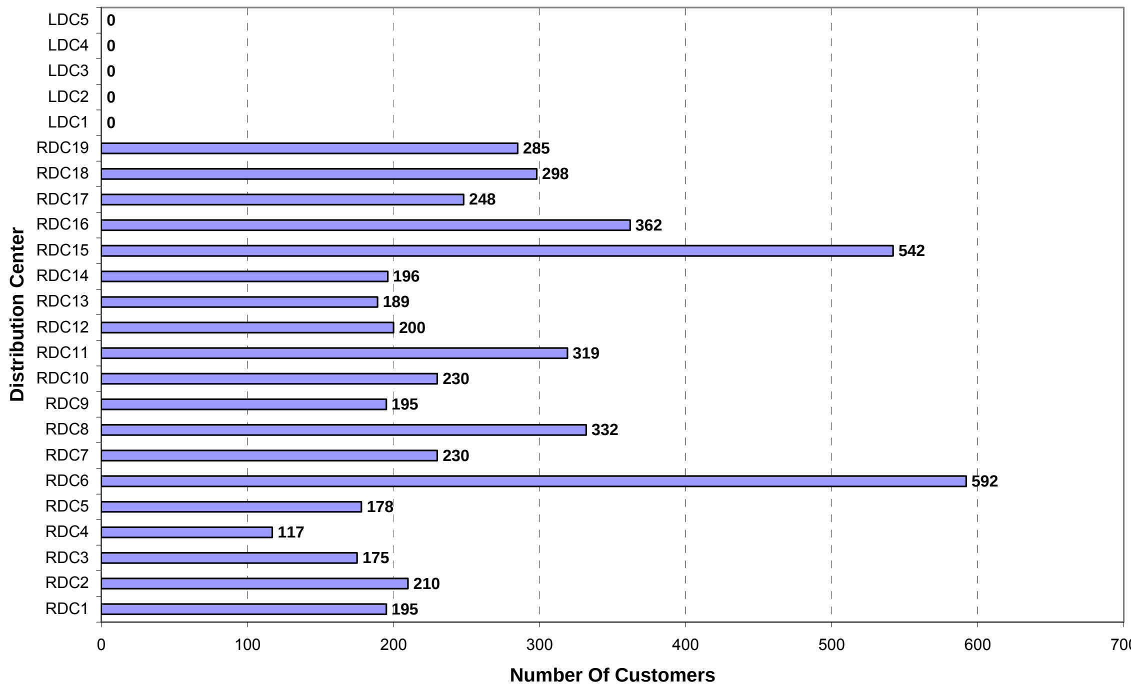

Figure 3. 13 Number of Customers per Distribution Center

The average daily demand for each item is aggregated and fitted to some of the theoretical probability distributions by using Input Analyzer. The Input Analyzer is a standard tool that accompanies ARENA software and is designed specifically to fit distributions to observed data, provide estimates of their parameters, and measure how well they fit into the data. In addition, the Input Analyzer provides three numerical measures of the quality of fit of a distribution to the data. The first, and the simplest to understand, is the *mean square error*. This is the average of the square error terms for each histogram cell, which are the squares of the differences between the relative frequencies of the observations in a cell and the relative frequency for the fitted probability distribution function over that cell's data range. The larger this square error value, the further away the fitted distribution is from the actual data (and thus the poorer the fit). The other two measures of a distribution's fit to the data are the chi-square and Kolmogorov-Smirnov (K-S) goodness-of-fit hypothesis tests. Kelton et al. [KSS02] gives more information about these tests and the Input Analyzer.

Figure 3.14 shows the aggregated daily average demand, the standard deviation, and the coefficient of variation (CV). Table 3.18 presents the fitted probability distribution with the square error for each distribution centre.

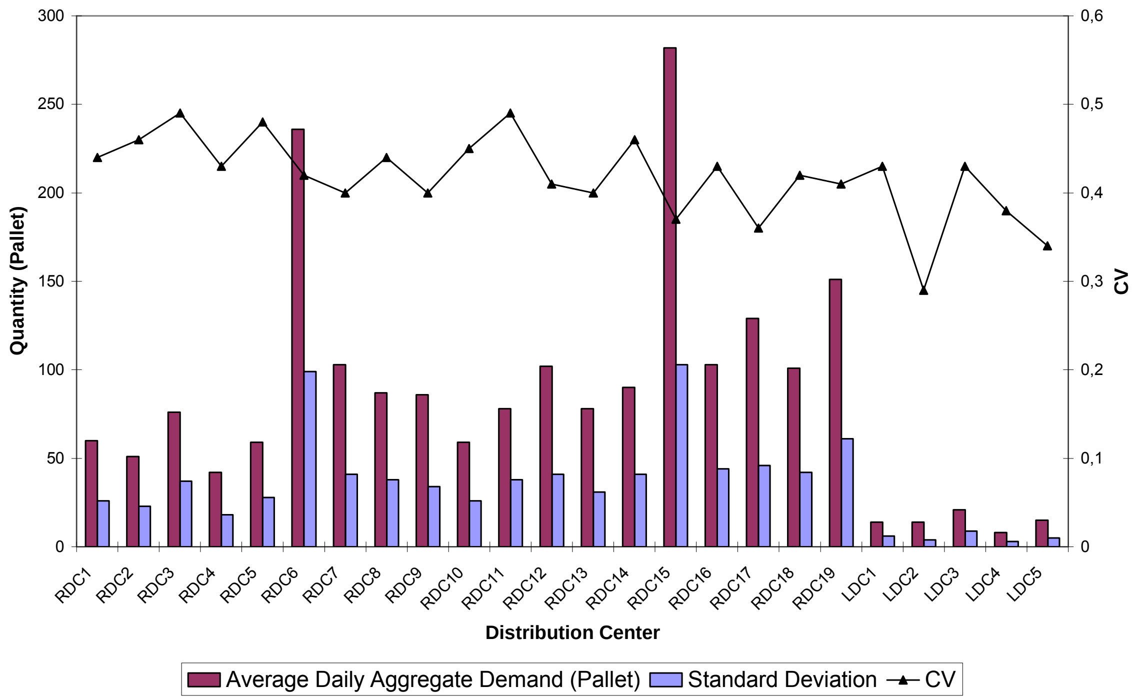

Figure 3. 14 Aggregated Average Daily Demand

Table 3. 18 Fitted Probability Distribution per Distribution Center

DC	Probability Distribution	Square Error
RDC1	Gamma	0.005490
RDC2	Erlang	0.005352
RDC3	Weibull	0.005104
RDC4	Lognormal	0.004430
RDC5	Gamma	0.010967
RDC6	Normal	0.009840
RDC7	Normal	0.008318
RDC8	Normal	0.004959
RDC9	Normal	0.003856
RDC10	Normal	0.009327
RDC11	Gamma	0.006381
RDC12	Gamma	0.007801
RDC13	Beta	0.010409
RDC14	Normal	0.007741
RDC15	Normal	0.005139
RDC16	Normal	0.006693
RDC17	Normal	0.005081
RDC18	Normal	0.008071
RDC19	Normal	0.003365
LDC1	Lognormal	0.007407
LDC2	Poisson	0.005243
LDC3	Lognormal	0.005141
LDC4	Beta	0.006377
LDC5	Erlang	0.005882

The percentage of each probability distribution of demand are calculated from the above Table and shown in Figure 3.15

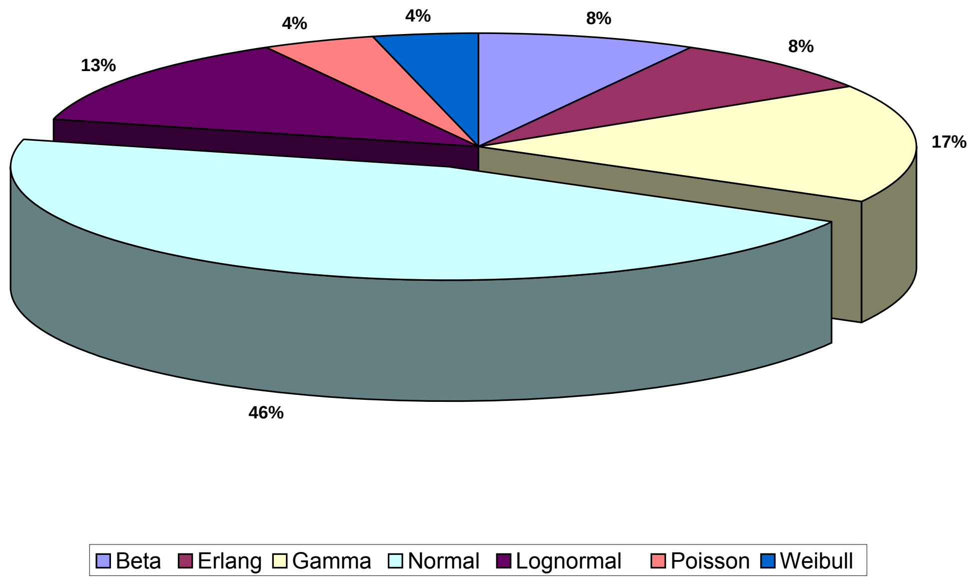

Figure 3. 15 Percentage of each Probability Distribution of Demand

When dealing with real supply chain problems, one of the important aspects is to consider whether the different items are homogeneous in terms of demand (demand variability). Demand variability ranges widely in different industries. For example, daily demand variability may be low (CV = 0.1 to 0.3) in consumer products but significantly higher in electronics products due to short product life cycles [WJD99]. To see the complexity and sensitivity of the considered real model, an analysis of demand data for individual items has been performed to evaluate the differences between items. The demand generated at the DC as real demand is considered.

A daily total average demand and standard deviation of 2546 items has been calculated, and then the CV is calculated and is shown in Figure 3.16.

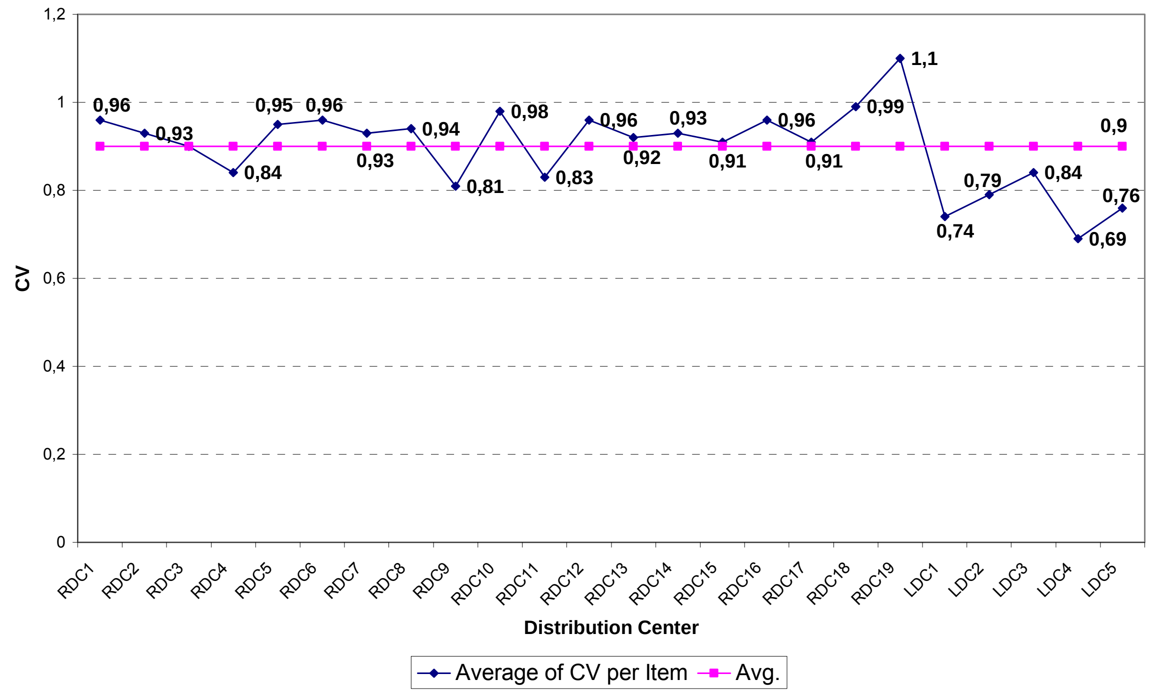

Figure 3. 16 Average of the Coefficient of Variation per Item for each Distribution Center

As can be seen from Figure 3.16, the CV of each item is higher than 0.5. This means that the demand variability is significantly high. Therefore, the considered real model is very sensitive and complex.

3.6.2.3. Lead Times

The lead times between locations (Warehouses and Distribution centres) are assumed to be uniformly distributed from 1 to 4 working days.

3.6.2.4. Logistics Cost Structure

In this study the most common (practice) and complex logistics cost structures have been considered. The logistics costs can be classified as follows:

- Transportation costs: The transportation cost is the most complex cost structure. A detailed transport cost matrix from the company has been considered for the computation of the transport costs based on different calculation criteria. The criteria depend on the number of pallets, weight, and distance (ZIP code and region). Freight rate discounts are offered based on these criteria and considered in the simulation model. The distance matrix between all the warehouses and distribution centres is shown in Table 3.19. The reduction of transportation cost (%) offered by Third Party Logistics (3PL) provider from warehouse 2 to three distribution centre (RDC9, RDC13 and RDC19) is explained in Table 3.20.
- Storage and handling costs (inventory costs)
    - a) Monthly storage costs
    - b) Order costs
- Activity-Based Costs
    - c) Order picking costs per pallet
    - d) Warehouse outgoing goods costs per pallet
    - e) Regional distribution centres incoming goods costs per pallet
- Toll fees
    - f) Inbound toll costs (warehouse to distribution centres) per kilometre travelled.
    - g) Outbound toll costs (distribution centres to retailers and customers) per kilometre travelled.

Table 3. 19 Distance Matrix in Kilometers

DC	Warehouse(1)	Warehouse(2)	Warehouse(3)
RDC1	519	653	285
RDC2	443	647	214
RDC3	448	549	267
RDC4	386	430	204
RDC5	283	521	127
RDC6	0	270	257
RDC7	322	192	388
RDC8	397	596	163
RDC9	300	58	473
RDC10	250	258	236
RDC11	525	467	404
RDC12	580	451	589
RDC13	596	697	398
RDC14	137	358	152
RDC15	92	183	296
RDC16	226	136	383
RDC17	239	401	57
RDC18	257	443	0
RDC19	438	195	552
LDC1	590	691	399
LDC2	513	270	636
LDC3	195	104	362
LDC4	685	555	561
LDC5	488	539	306

Table 3. 20 Reduction in Transportation Cost (%) Matrix

Warehouse Nr.	Pal min	Pal max	Distribution Center Nr.		
			RDC9	RDC13	RDC19
2	1	1	0,00%	0,00%	0,00%
2	2	2	33,91%	5,68%	34,78%
2	3	3	41,96%	11,36%	41,30%
2	4	4	51,96%	21,59%	43,48%
2	5	5	59,13%	37,50%	46,74%
2	6	6	63,91%	40,11%	47,39%
2	7	7	67,39%	42,05%	50,22%
2	8	8	70,00%	44,20%	53,48%
2	9	9	72,61%	45,68%	56,09%
2	10	10	74,78%	46,14%	58,04%
2	11	11	76,96%	47,16%	60,65%
2	12	12	78,26%	48,64%	62,39%
2	13	13	79,13%	50,68%	63,70%
2	14	14	79,78%	51,14%	65,00%
2	15	15	80,22%	54,07%	66,09%
2	16	16	80,87%	54,89%	67,61%
2	17	17	81,30%	56,14%	68,91%
2	18	18	81,52%	56,59%	70,22%
2	19	19	81,96%	56,59%	71,30%
2	20	20	82,17%	56,82%	72,17%
2	21	21	82,83%	57,05%	73,48%
2	22	22	83,48%	57,16%	74,35%
2	23	23	84,13%	57,27%	75,22%
2	24	24	84,78%	57,39%	76,09%
2	25	25	85,00%	57,39%	76,74%
2	26	26	85,00%	57,50%	76,96%
2	27	27	85,22%	57,50%	77,17%
2	28	28	85,43%	57,50%	77,39%
2	29	29	85,65%	57,61%	77,61%
2	30	30	85,87%	57,61%	77,83%
2	31	31	86,09%	57,73%	78,04%
2	32	32	86,30%	57,84%	78,48%
2	33	33	86,52%	57,95%	78,70%
2	34	34	86,74%	58,64%	78,91%
2	35	35	86,96%	59,09%	79,13%
2	36	36	86,96%	59,55%	79,35%
2	37	37	87,17%	59,77%	79,78%
2	38	38	87,39%	60,23%	80,43%

As can be seen from Table 3.20, as the number of shipped pallets is increased the transportation cost is reduced. The percentage of this reduction varies for each warehouse and for each distribution center. More analysis will be discussed in Chapter 5.

3.6.3. Problem Description

Due to increasing logistics costs and due to considerable competition in the market the company wants to build and use a simulation model to study and investigate many different optimizing decisions regarding distribution network structures and distribution strategies. The company is also interested in studying the proper measures of performance that should be used. A primary objective was to maintain or improve service levels, while reducing inventories and transportation costs. A project team used simulation to quantify how well alternative networks would function through variations in demand and supply. The company designed some different scenarios and requires the following questions to be answered by the simulation model:

1. Is the existing distribution network well designed?
2. What is the optimal distribution network from the proposed scenarios?
3. How should new cost structures be considered and evaluated?
4. What is the relationship between distribution strategies and the resulting inventory levels, customer service levels, and number of replenishments?
5. Does the location of inventory storage for different classes of item have an effect on the total inventory levels and number of tours?

The logistics manager in the company had to study some operating strategies to evaluate and improve the existing network. The simulation study was designed to investigate these strategies.

3.6.4. Simulation Model and Assumptions

The main objective of applying the simulation was the investigation of different operating strategies at the warehouses and regional distribution centres to improve the efficiency of the distribution network in the supply chain. The simulation model which has been developed and described at the beginning of this chapter is implemented. Figure 3.17 illustrates a snapshot screen of the simulation model.

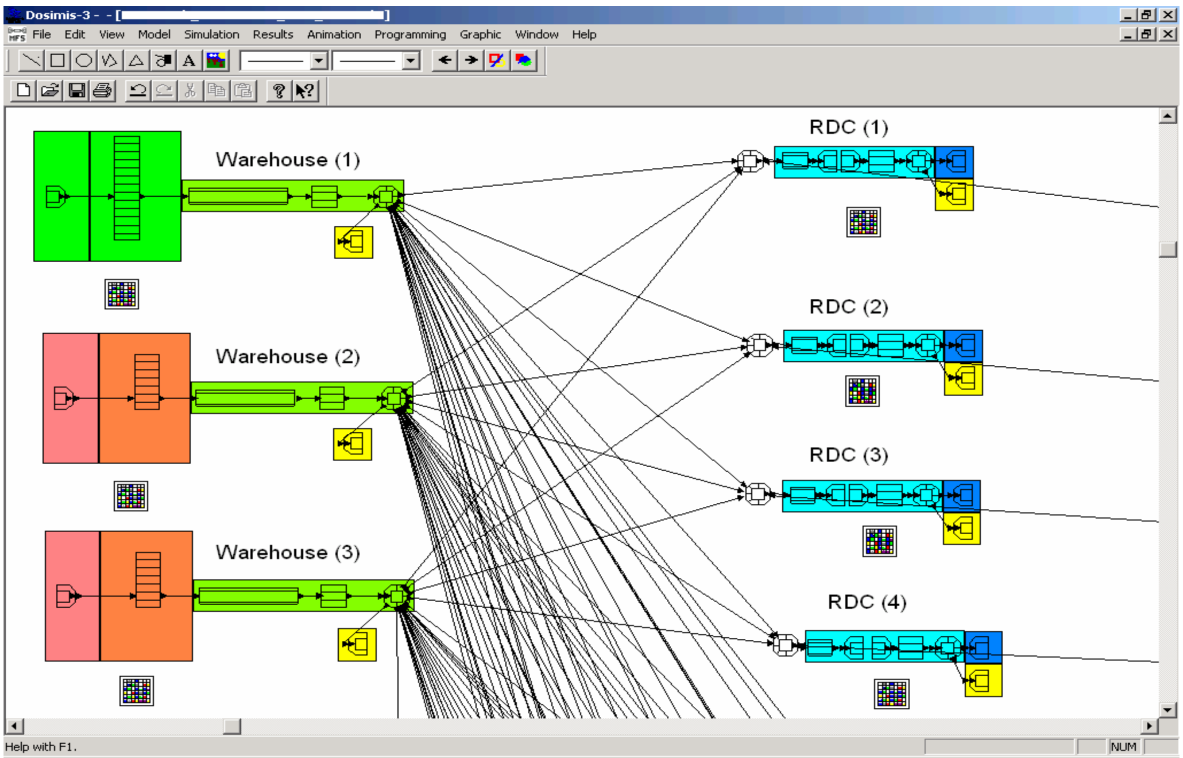

Figure 3. 17 DOSIMIS-3 Simulation Model Snapshot

3.6.4.1. Simulation Assumptions

The developed simulation model was implemented under the following assumptions:

- Standard European Pallet (SEP) with a height of 2.4 m height will be used to move the full pallet product from the warehouses to regional distribution centre.
  Length x Width x Height (LxWxH) = 1.2m x 0.8m x 2.4m
- The mixed pallet of the following dimensions will be used to move the product from the regional distribution centre to retailers and customers :
  L x W x H = 1.2m x 0.8m x 1.8m. Percentage of utilized space: 70%
- Transportation costs based on the direct tour with one destination will be accounted, no routing allowed.
- Direct shipments from central warehouse to retailers or customers are allowed if the shipment size is up to truck capacity.
- The used truck capacity is 38 SEP
- All transportations between locations are done by Third Party Logistics (3PL) providers. Therefore the fixed transportation costs are not considered.
- The customer orders are satisfied and delivered completely (all order lines) based on a first-in-first-out (FIFO) rule.

3.6.5. Simulation Experiment and Results

Simulation results are collected after running the developed simulation model for one year. The validation of the model has been accomplished by comparing the simulated results with the historical data provided by the logistic department in the company. The data collected for each scenario is exported to an Excel worksheet after the simulation run is completed. Noche et al. [NAH04] gives more detailed information about these scenarios, the answer to the previously raised questions, and the findings.

3.7. Extended Studies and Models

Coordination and Integration are the key terms for effective supply chain management. An effective supply chain will reduce the systemwide costs while improving the service levels and conforming to customer requirements.

In last few years, as many companies become aware of their supply chain performance and the importance of their performance improvement, coordination and integration of the inventory and the distribution strategies have become the other source of competitive advantages. They have also realized that important cost savings can be achieved by integrating inventory control and transportation policies throughout their supply chains. Thus, the problem faced by these companies is to find an optimal replenishment plan, i.e. an inventory and transportation strategy, so as to minimize total inventory and transportation costs over a finite planning horizon [CMS02].

The problem has attracted the attention of researcher in recent years and many models have been proposed in this direction. The basic idea behind these models is to simultaneously optimize decision variables of different stages that have traditionally been optimized sequentially, in the sense that the optimized output of one stage becomes the input to the other stage (first setting inventory levels and then scheduling distribution, for instance). Since the problem is so complex that optimal solutions are very difficult to obtain. Due to this reason most of the study models consider simple networks and make many assumptions, such as, only considering direct shipment, in order to simplify the problem, and thus, it can be solved by exact algorithms (mixed integer programming) and heuristic solution approaches.

Integrated inventory replenishment and order shipment consolidation have received much attention recently, driven mainly by the widespread adoption of Vendor Managed Inventory (VMI) programs. Under a typical VMI program, the supplier/vendor holds a certain level of control not only over in-bound replenishment decisions on stocking, but also over outbound re-supply decisions on the timing and/or quantity of shipment consolidation. Thus, the trucks are more likely to be dispatched fully, and the vendor has a better opportunity to synchronize the inventory and transportation decisions. However, the challenge is to satisfy demanding customer service standards if they are justified, while at the same time the benefits of consolidation are achieved.

Generally, to solve such integrated problems optimally and to implement such concepts is not easy due to their combinatorial and dynamic nature, especially when many strategies are involved in a real supply chain.

Simulation models that permit user interaction and take the dynamics of the system in to account are capable of characterizing system performance for integrated models.

The previous open problems and new concepts regarding these problems are mainly the scope of work of this thesis. Many extended studies and experiments have been constructed and conducted. In the next sections, detailed description of the extended studies of the case study and the developed simulation model will be introduced.

3.7.1. Investigation of Coordinating Distribution Strategies and Inventory Policies Study

The goal of this work is the study of the integrated inventory and distribution problem which is concerned with coordinating the inventory and delivery operations to meet customer demand with an objective to minimize the total logistic costs. The developed simulation model is used to investigate the effect of coordination and integration of inventory policies and distribution strategies on the selected measures of performance and also to see how significantly the coordination affects the selected measures of performance.

In this study, the existing distribution supply chain network is extended to be more complex. The considered network consists of three echelons (Warehouse, distribution centre, and special retailer). Many simulation scenarios have been designed and many statistical tests have been performed to see how significantly the coordination affects the selected measures of performance.

The results from statistical test approach suggest that the inventory policies and shipping (distribution) strategies significantly affect the measures of performance of the supply chain network. The investigations also show that integrating the inventory policies and transportation strategies is not simple. It requires a trade-off between different performance measures. Potential costs saving can be achieved by selecting the right inventory policy and transportation strategy. The complete benefit of coordination is only achieved when all the stages and functions in the entire network are integrated. Housein et al. [HAN05] gives more detailed description of this work. The results of this study clearly conform to intuition and help to verify the internal consistency of the developed simulation model. There are many opportunities for expansion of the simulation model presented in this study. The open areas where model expansion would be of benefit are discussed and carried out in the subsequent sections of this thesis.

3.7.2. Coordination Strategies Model Study II

One of the current interests in supply-chain management is to overlook certain transportation/distribution issues; potential savings are realizable by carefully coordinating a shipment strategy with the inventory replenishment policies. This effect is particularly tangible when the shipment strategy calls for a consolidation program where several smaller deliveries are shipped as a single load, realizing substantial savings in transportation costs.

Formally, shipment consolidation refers to the active intervention by management to combine many small shipments/orders so that a larger, hence more economical, load can be sent on the same vehicle [Bre81], [Hal87], [HB95]. The main motivation behind a consolidation program is to take advantage of the decreased per unit freight costs due to economies of scale associated with transportation [CL00]. Based on that two heuristic, consolidation concepts are developed and programmed to integrate into the developed simulation model. These two are:

1. Item classification consolidation concept
2. N-days forecasted demand concept

The flow logical processes for both consolidation concepts are illustrated in Figure 3.18.

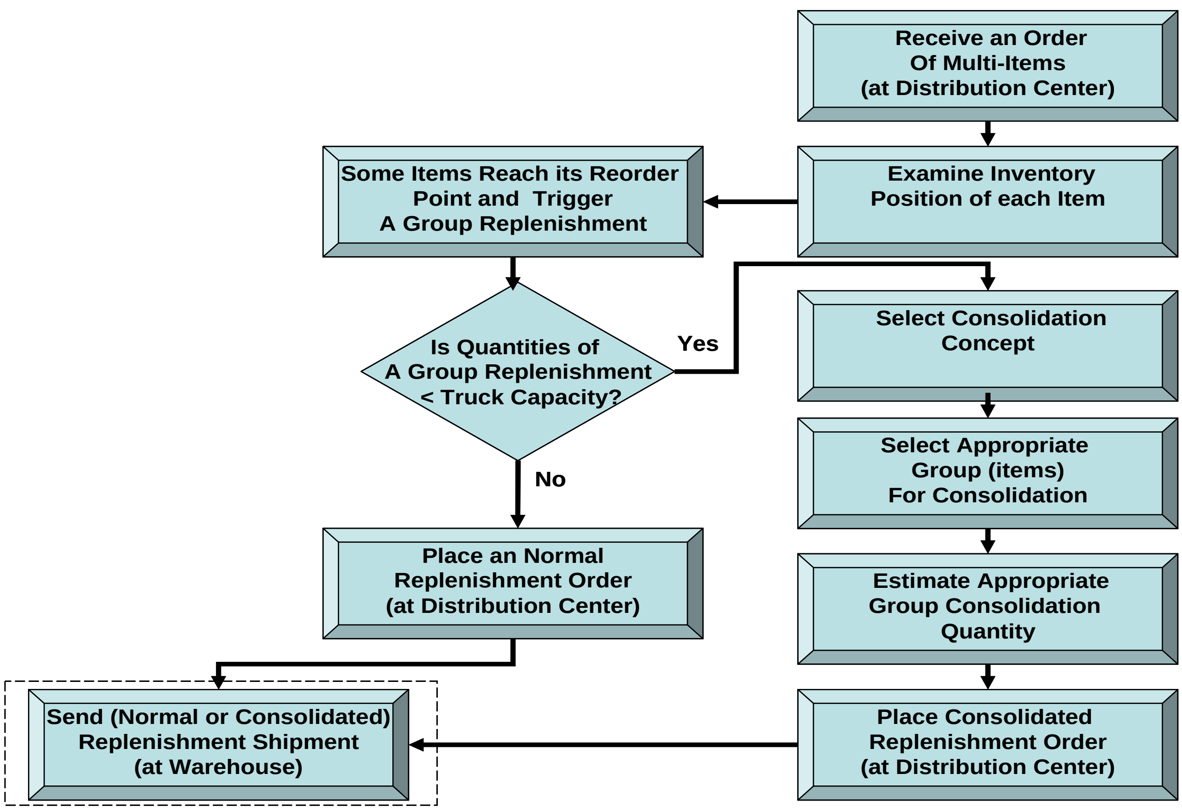

Figure 3.18 Flow Logical Processes of Consolidation Concept

3.7.2.1. Notation

QR_j = replenished quantity for item j in pallet unit.

QC_i = consolidated quantity for item i in pallet unit.

Q_{iD} = customer order quantity for item i (in pallet unit) of one day.

Q_{iN} = sum of order quantities for item i (in pallet unit) of the next N-days.

Tr_C = truck capacity.

Tr_{EC} = empty truck capacity.

I_i = inventory position for item i.

s_i = reorder point

RL= replenishment list.

CL= consolidation list.

NDL= N-days list.

CNDL= candidate items N-days list.

FCL= final consolidation list.

FCNDL= final consolidation of candidate items list.

n = number of items.

N = total number of days.

The two consolidation concepts are constructed under the following two assumptions:

- The replenished quantity (QR_j) and consolidated quantity (QC_i) rounded up to make full pallet per item type, and the minimum quantity is one pallet.
- The total quantities of group replenishment are less than the truck load (truck capacity).

For more understanding of the consolidation concepts, some steps are summarized. In the following section, the steps of the consolidation concepts are presented.

3.7.2.2. Item (Article) classification consolidation concept

The proposed consolidation concept consists of the following steps:

STEP 1: Review the inventory position of items in all the orders after receiving the customer orders and let:

RL = {items to be replenished sorted in FIFO rule, such that $I_i < s_i$},

for ($j = 1,2,........,n$).

STEP 2: Review the truck capacity

If $\sum_{j \in RL} QR_j < Tr_C$ (This equation should be satisfied to apply the consolidation concept)

Then

Go to STEP 4

Else

Go to STEP 3

STEP 3: Order QR_j for each element in RL. EXIT. (normal replenishment)

STEP 4: Let: CL = {items to be consolidated sorted in descending order according to the ABC classification}, such that ($i = 1,2,........,n$).

CL = {[1], [2], [3], [4], …………………….., [k]}

STEP 5: Let: $Tr_{EC} = Tr_C - \sum_{j \in RL} QR_j$

STEP 6: Let: FCL= {first t elements in CL ($t \ldots\ldots k$)} such that:

for $t \le k$ $\sum_{i=1}^{t} QC_i \le Tr_{EC}$

STEP 7: Check,

If $\sum_{i=1}^{t} QC_i = Tr_{EC}$

Then

Go to STEP 9

Else

Go to STEP 8

STEP 8: For each i in FCL, let:

$QC_i = 1 + QC_i$, before applying this equation to the next i,

Go to STEP 7

STEP 9: Order QR_j for each element in RL and QC_i for each element in FCL. EXIT. (consolidated replenishment)

Note:

- The initial value of QC_i = One pallet

From this concept, four consolidation concepts are developed:

1. ABC-Articles (Items) type Consolidation Concept.
2. A-Articles (Items) type Consolidation Concept.
3. C-Articles (Items) type Consolidation Concept.
4. Z-Articles (Items) type Consolidation Concept.

The only different between the above concepts is in the step 4. The criteria used for ranking the items in CL should be changed based on the item classification used. For example, in the first concept the ABC classification is used; in the second concept the A items from the ABC classification are used; in the third concept the C items from ABC classification are used; and in the fourth concept the Z items from ABC-XYZ classification are used and items are ranked as ZA, ZB, and ZC. Chapter 4 gives more information on these classifications.

In this concept, there is guarantee that the replenishment quantities will generate a full truckload (STEP 8).

3.7.2.3. N-Days forecasted demand consolidation concept

Advance demand information is one of the technologies provided by supply chain partners. This is when customers with positive demand lead times place orders in advance of their needs, this results in what is called advance demand information.

Ford Motor Company, for example, issues and weekly updates orders to its catalytic converter suppliers, as discussed in the “Corning Glass Works” Harvard Business School teaching case (1991). The e-commerce of customized products, such as personal computers, provides advance demand information for the product components. An example is Dell’s cutting edge distribution model. Under this model, consumers are allowed to customize their choice of PC online for future delivery [HS99].
Toyota recently announced plans to make customized cars within five days, reflecting its ability to quickly respond to advance demand information [Sim99]. GM and Ford are scrambling to catch up this trend. These strategies, in conjunction with advances in information technology, assist companies in getting a better sense of demand and its evolution over time.

Advance demand information enables many companies to shift their production operations from the ‘build to stock’ to ‘build to order’ model. In spite of the fact that many companies operate in a dynamic environment, stochastic inventory models that incorporate advance demand information are rare [GÖ01].

In addition, advance information technology allows supply chains to be designed to satisfy most of the conflicting goals. For example, when shipments are delivered in full truckloads, this is done to minimized transportation costs, and at the same time, it leads to higher inventory costs. Such conflicting cases can be reduced by using advance information technology [SKS03]. In this thesis, this fact has been implemented by applying the developed consolidation concept (N-Days forecasted demand consolidation).

The proposed concept for the consolidation is modified to consider the above technology and consists of the following steps:

STEP 1: Review the inventory position of items in all the orders after receiving the customer orders and let: RL = {items to be replenished, sorted in FIFO rule, such that $I_i < s_i$}, for ($j = 1,2,........,n$).

STEP 2: Review the truck capacity

If $\sum_{j \in RL} QR_j < Tr_C$ (This equation should be satisfied to apply the consolidation concept)

Then

Go to STEP 4

Else

Go to STEP 3

STEP 3: Order QR_j for each element in RL. EXIT. (normal replenishment)

STEP 4: Read all orders for the next N-days for each DC from the order customers list.

Let: NDL = {items to be ordered in N-days ranked by event time, following chronological order}, for ($i = 1,2,........,n$).

STEP 5: Sum all the order quantities for the same item at the same location.

Let: $Q_{iN} = \sum_{D=1}^{N} Q_{iD}$ for each i in NDL

STEP 6: Check, for each i in NDL

If $Q_{iN} > I_i$

Then

Go to STEP 7

Else

Go to STEP 6

STEP 7: Let: CNDL= {candidate items for consolidation, such that $Q_{iN} > I_i$}, for ($i = 1,2,........,n$)

If CNDL= {ø} then Go to STEP 3

STEP 8: Rank the k items in CNDL following the same sequence in NDL, such that: CNDL= {[1], [2], [3], [4],………….[k]}

STEP 9: For each i in CNDL set:

$$QC_i = Q_{iN}$$

STEP 10: Let:

$$Tr_{EC} = Tr_C - \sum_{j \in RL} QR_j$$

STEP 11: Let: FCNDL= [first t elements in CNDL (t …..k)} such that

for $t < k$

$$\sum_{i=1}^{t} QC_i \le Tr_{EC} \quad \text{and} \quad \sum_{i=1}^{t} (QC_m + QC_i) > Tr_{EC}$$

for each $m > t$ and m in CNDL

Go to STEP 12

for $t = k$:

$$\sum_{i=1}^{t} QC_i \le Tr_{EC}$$

Go to STEP 13

STEP 12: Let $QC_m = Tr_{EC} - \sum_{i=1}^{t} QC_i$ (m is the last item in FCNDL)

STEP 13: Order QR_j for each element in RL and QC_i for each element in FCNCL.

EXIT. (consolidated replenishment)

As mentioned before, this concept is constructed under an important assumption. The assumption is:

- Advance information about the order of customers is incorporated.

This assumption is valid because many companies in the industry ask customers to fix their demands some days before the delivery. Therefore, in this thesis, the concept using this technology is implemented.

Due to fact that information technology has developed in recent years and companies are seldom willing to incorporate such technology into the original consolidation concept, this technology is not considered. The original concept is constructed under another assumption:

- Forecasting techniques are used to forecast a demand in advance.

Therefore, Step 4 should be modified, and instead the order customers list should be read for n-days, by applying any forecasting technique, reading from the forecasted demand list for n-days.

Also, a discussion is held with the logistics manager in the considered company regarding the maximum period for which information is required from the customers in advance. The maximum period is not more than four days. Based on that two consolidation concepts are developed:

1. 2-Days Forecasted Demand Consolidation Concept.
2. 4-Days Forecasted Demand Consolidation Concept.

In this concept, there is no guarantee that the replenishment quantities will generate a full truckload. More detailed information about the classification of items and the application of the consolidation concepts is described in the next chapter.

3.7.3. VMI-Programs Model Study II

In this study, a simulation model for coordinating inventory and transportation decisions in VMI systems is presented. The mechanism driving order placement is the only modification made for the developed simulation model. Instead of the distribution centre placing orders with the warehouse (supplier), the warehouse obtains customer orders directly, bypassing the distribution centre. In turn, the warehouse determines the quantity and timing of goods sent to the distribution centre, and the distribution centre functions primarily not only as a transport delay in the system, (transshipment point) but also as a rearrangement for the tours.

Note that the distribution centre no longer places orders with the warehouse. Distribution centre inventory is depleted at a rate, by retail shipping, which is equal to customer demand.

To reflect the vendor-managed inventory concept by using the developed simulation model, the user should select the appropriate inventory policy and replenishment policy for each location in the network. For example, the downstream locations should be selected as distribution centres with “Not allowed to keep inventory” inventory policy. In this case, the distribution centres function as transshipment points and all the inventory decisions are taken at upstream locations (warehouses).

To make the coordination between the inventory policies and transportation strategies more efficient, the VMI concept could be integrated with one of the above described consolidation concepts. Since the user selects “Not allowed to keep inventory” inventory policy for a location, he should also select one of the consolidation concepts as the replenishment policy. All of these strategies could be selected through the input data mask parameters (Figure 3.19).

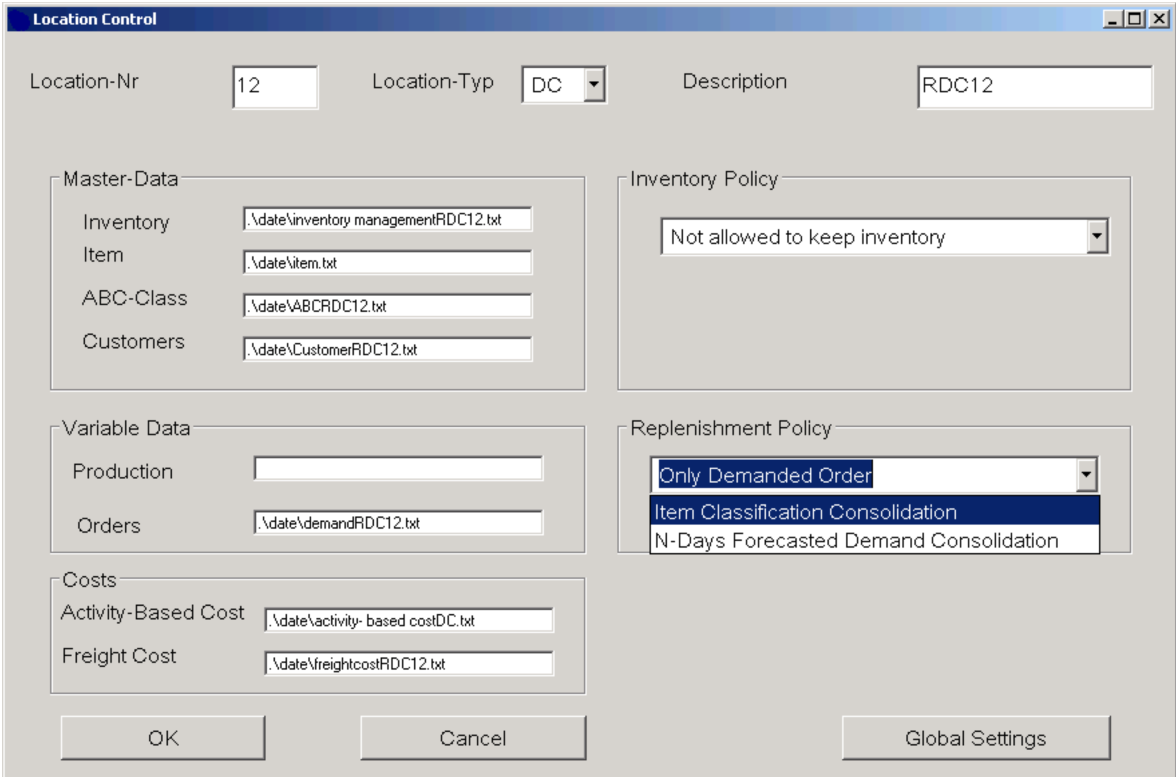

Figure 3. 19 Mask Parameters for VMI and Consolidation Concepts

The flow of logical processes of consolidation concepts under VMI model is shown in Figure 3.20.

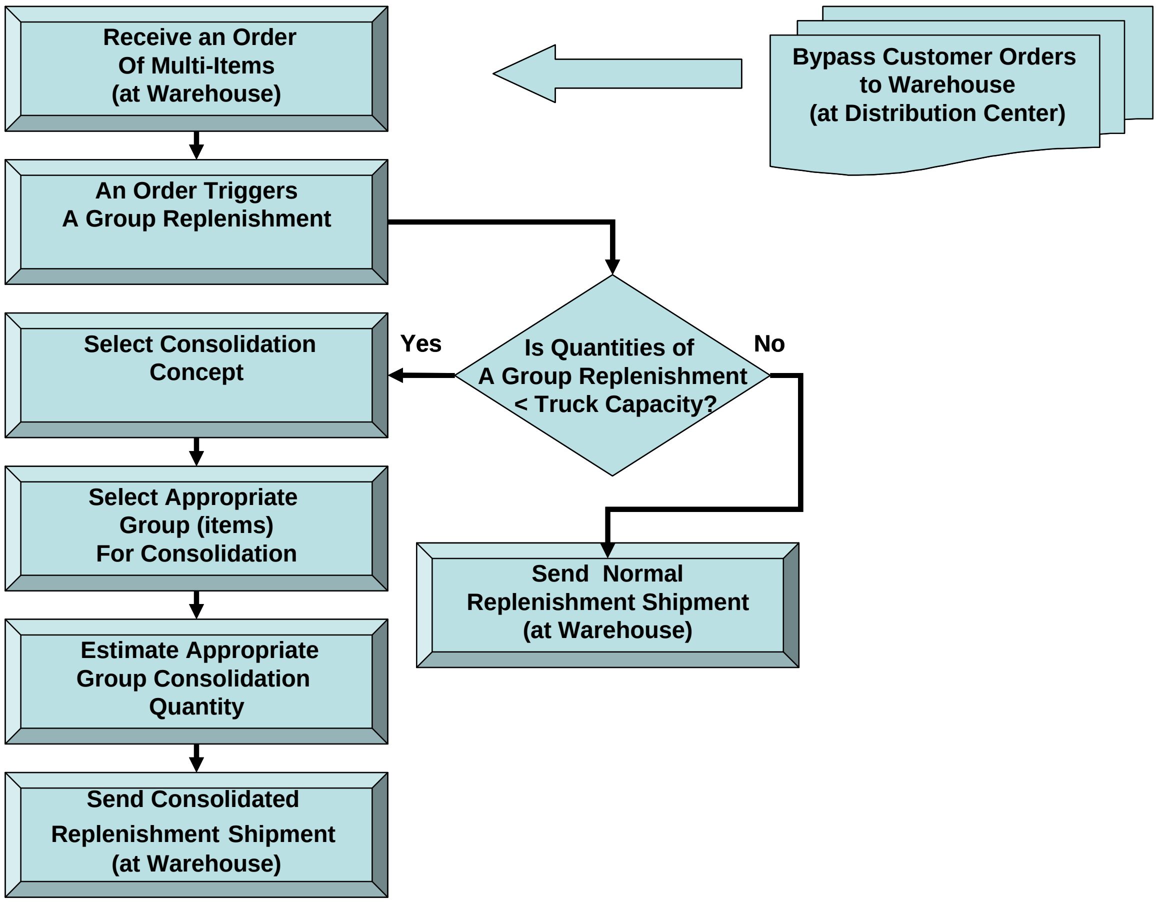

Figure 3. 20 Flow of Logical Processes of Consolidation Concept under VMI Model

The application of the above model and its concepts will be presented in the next chapters. Finally, to implement the simulation model of any designed strategy, appropriate operating strategies should be selected. The operating strategies of the simulation models for each strategy design in the next four chapters are summarized and illustrated by Table 3.21.

Table 3. 21 Operating Strategies of the Simulation Model

Operating Strategy		UCS	CS	UCS-V	CS-V
Inventory Policy	with Allowed to keep inventory	X	X		
	Not allowed to keep inventory			X	X
Replenishment Policy	FTL Concept (Consolidation Concepts)		X		X
	LTL Concept (Only Demanded Order)	X		X	

UCS: Uncoordinated Strategy

CS: Coordination Strategy

UCS-V: Uncoordinated Strategy with VMI approach

CS-V: Coordination Strategy with VMI approach

FTL: Full Truckload

LTL: Less than Truckload.

4. Design and Analysis of Uncoordinated Distribution Strategies: Item Classification approaches

The aim of this chapter is to show the sensitivity of distribution strategies in supply chains to item classification approaches and to show the difficulties of optimizing such complex systems, due to the conflicts of system objectives. To achieve the aim, the developed simulation model is used and implemented.

4.1. ABC Classification, XYZ, and ABC-XYZ Classification approaches

In multi-item inventory systems, classification of inventories can help to reduce the complexity of managing thousands of items. Many researchers [FW87] recommend the use of a two dimensional classification systems, where the first is the traditional ABC classification and the second is based on criticality. In this thesis a two dimensional classification of items is used. The first is the traditional ABC classification and the second is based on variability (XYZ classification).

4.1.1. ABC Classification

ABC classification is a practical approach [EB94], [Bal04], [SKS03] applied for multi-item inventory problems. Different item classifications need different replenishment and inventory control policies. Different types of items also need different ways of replenishment. Silver et al. [SPP98] propose the so-called ABC-classification, based on the perception that items with a large turnover (A-items) need to be controlled differently compared with items with a low turnover (C-items).

In this classification approach, the items are classified based on demand (consumption) rate:

- ***A-Class:*** This class represents about 11 to 24% of the items carried in inventory and 75% of the consumption rate (***fast-moving items***).
- ***B-Class:*** This class represents about 13 to 23% of the items carried in inventory and 15% of the consumption rate.
- ***C-Class:*** This class represents about 55 to 75% of the items carried in inventory and 10% of the consumption rate (***slow-moving items***).

The classification has been done for all the distribution centers based on the real demand data from the company. The ABC classification of some distribution centers are illustrated in the following figures:

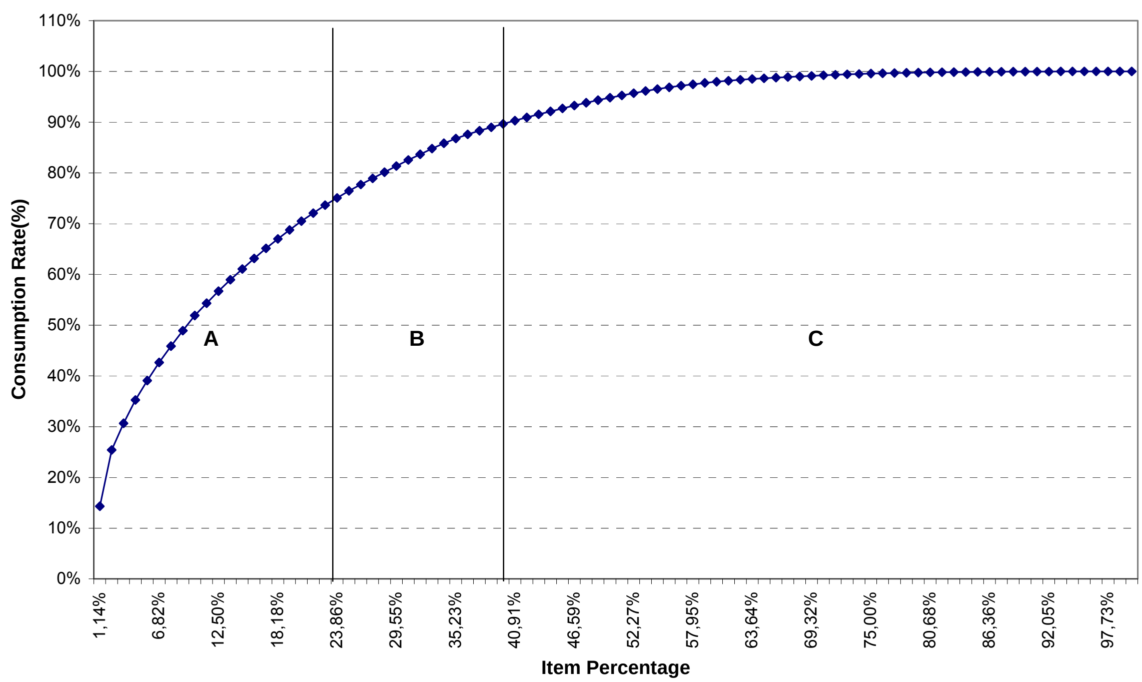

Figure 4. 1 ABC Classification for LDC1

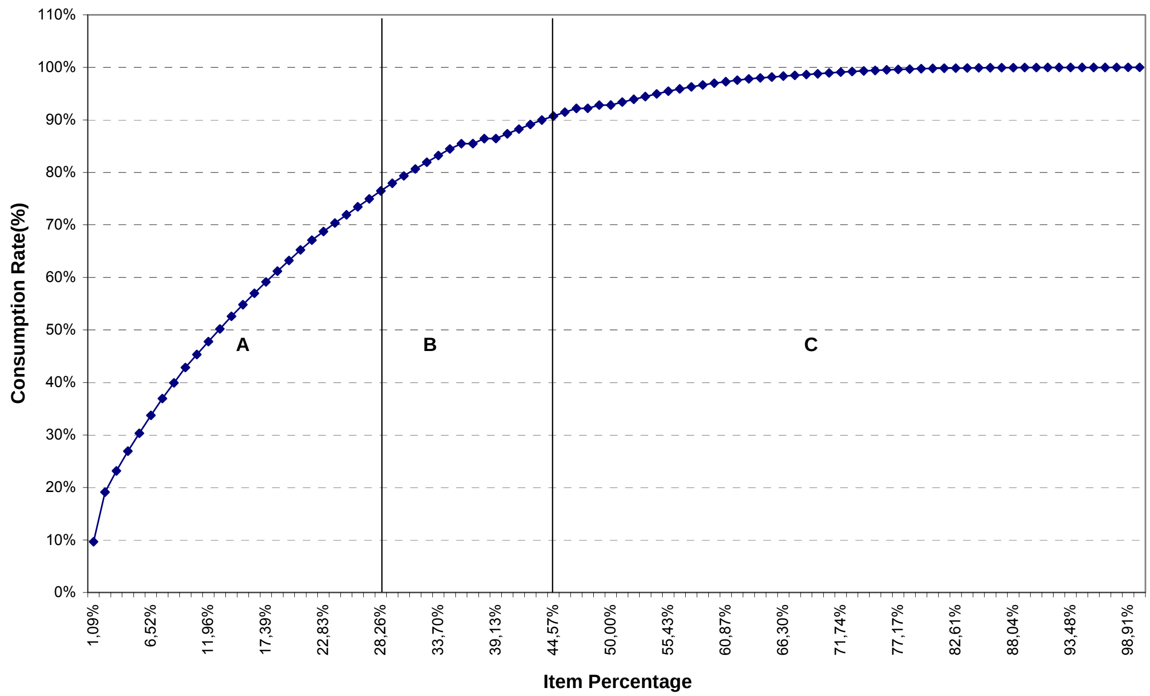

Figure 4. 2 ABC Classification for LDC5

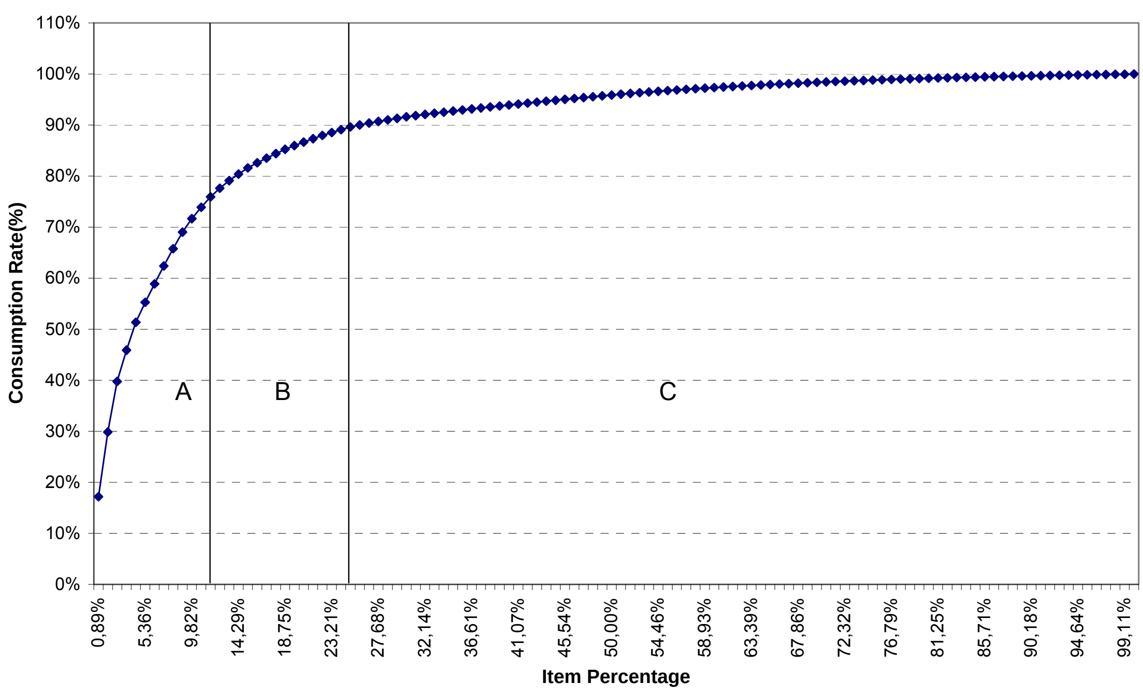

Figure 4. 3 ABC Classification for RDC15

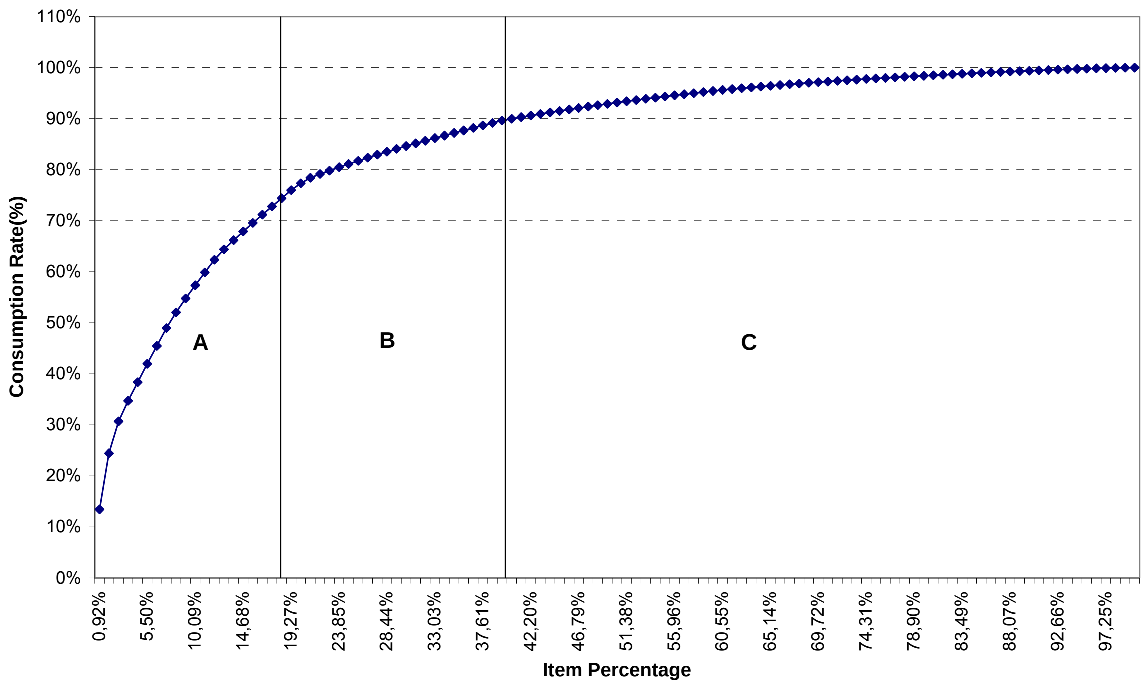

Figure 4. 4 ABC Classification for RDC19

Table 4.1 shows the percentage of items in each class for each distribution centre and Figure 4.5 shows the average percentage of items in each class for all the distribution centers.

Table 4. 1 Percentage of Items in each Class for each Distribution Center

DC	A	B	C	Total
RDC1	20,75%	19,81%	59,43%	100,00%
RDC2	17,59%	19,44%	62,96%	100,00%
RDC3	15,93%	18,58%	65,49%	100,00%
RDC4	22,12%	19,23%	58,65%	100,00%
RDC5	14,55%	17,27%	68,18%	100,00%
RDC6	12,69%	17,91%	69,40%	100,00%
RDC7	20,18%	15,79%	64,04%	100,00%
RDC8	15,60%	17,43%	66,97%	100,00%
RDC9	11,11%	19,44%	69,44%	100,00%
RDC10	24,55%	16,36%	59,09%	100,00%
RDC11	19,27%	17,43%	63,30%	100,00%
RDC12	24,30%	20,56%	55,14%	100,00%
RDC13	23,89%	17,70%	58,41%	100,00%
RDC14	15,65%	22,61%	61,74%	100,00%
RDC15	11,61%	13,39%	75,00%	100,00%
RDC16	12,50%	18,27%	69,23%	100,00%
RDC17	21,60%	15,20%	63,20%	100,00%
RDC18	21,50%	22,43%	56,07%	100,00%
RDC19	18,35%	21,10%	60,55%	100,00%
LDC1	22,73%	17,05%	60,23%	100,00%
LDC2	23,26%	15,12%	61,63%	100,00%
LDC3	18,29%	15,85%	65,85%	100,00%
LDC4	29,63%	18,52%	51,85%	100,00%
LDC5	28,26%	16,30%	55,43%	100,00%

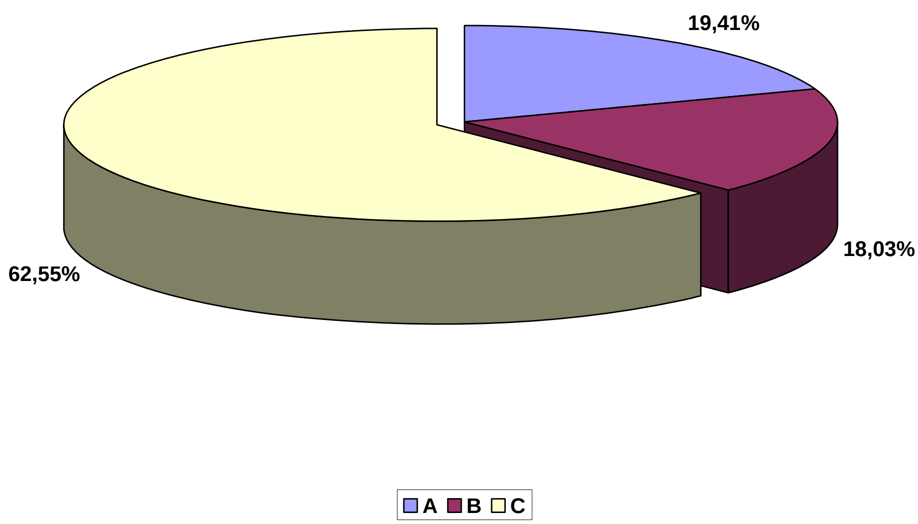

Figure 4. 5 Average Percentages of Items in each Class

4.1.2. XYZ Classification:

The variability of item demand (consumption) must be taken into consideration in order to improve the supply chain processes [Sch01], [RT02], [Knu03]. The items are classified based on demand variability. The variability is measured by the coefficient of variation (CV), the standard deviation of daily demand divided by the mean.

- ***X-Class:*** In this class daily demand variability is low (CV ≤ 0.5).
- ***Y-Class:*** In this class daily demand variability is intermediate (0.5< CV ≤ 1.0).
- ***Z-Class:*** In this class daily demand variability is high (CV > 1.0).

For an item with very low coefficient of variation, the demand can be forecasted with good accuracy. For an item with very high coefficient of variation, the demand can not be forecasted with accuracy.

As in the first classification, the XYZ classification has been done for all the distribution centers based on the real demand data from the company. The XYZ classification of some distribution centers are exhibited in the following figures.

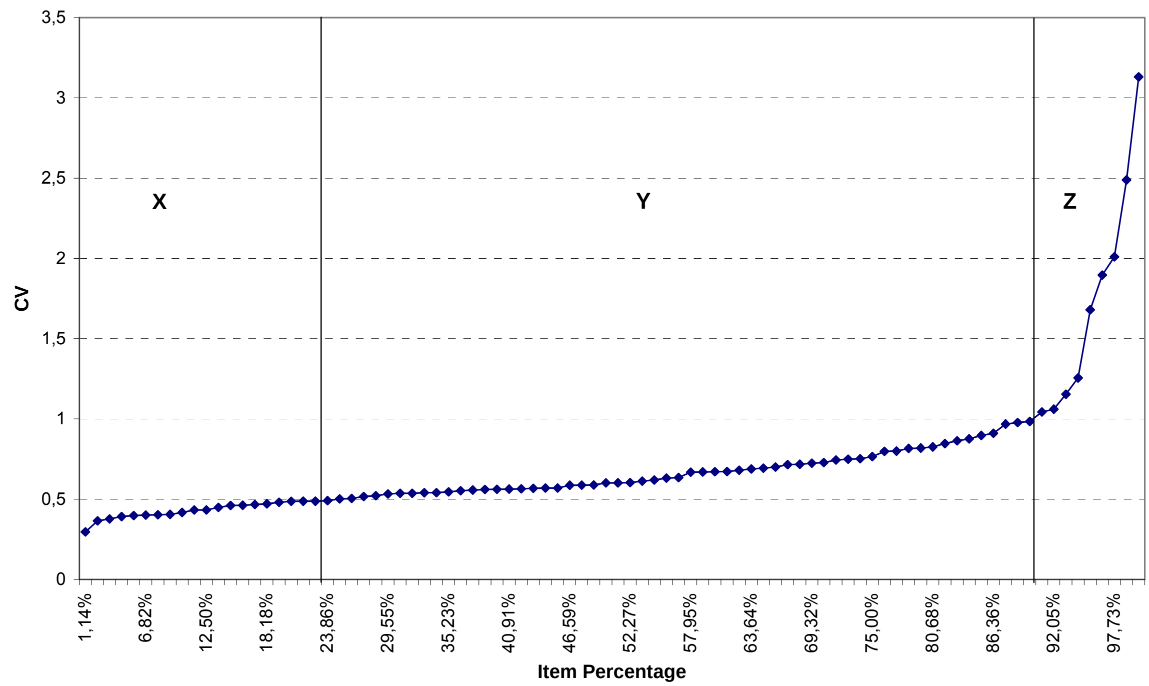

Figure 4. 6 XYZ Classification for LDC1

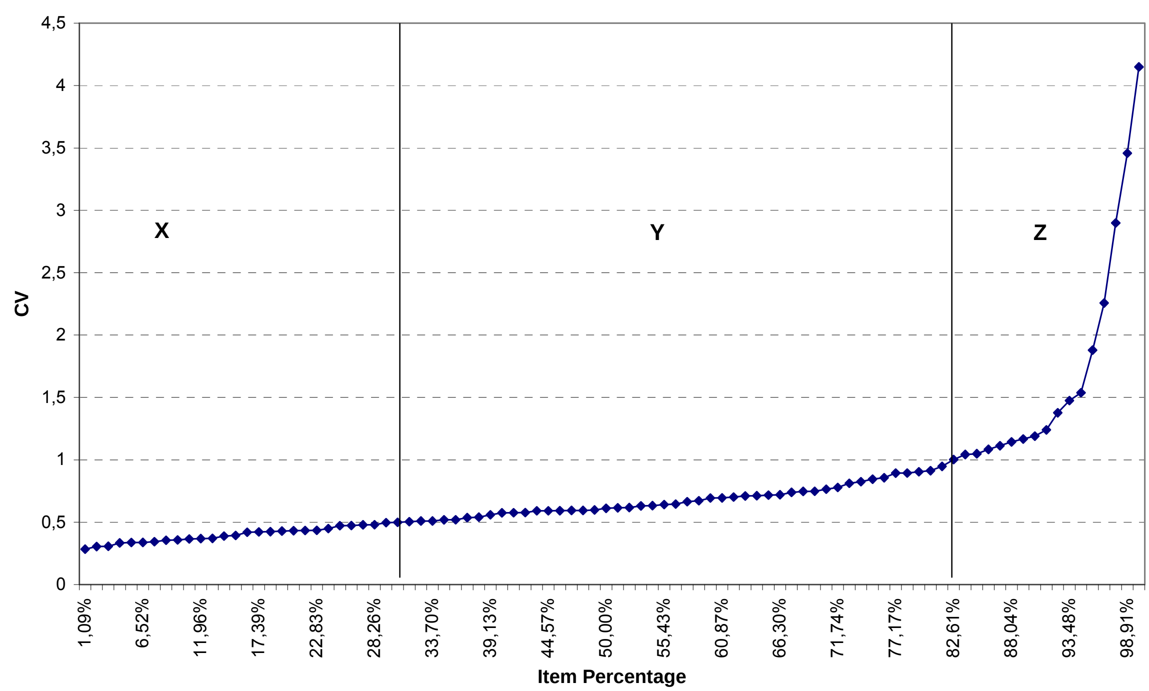

Figure 4. 7 XYZ Classification for LDC5

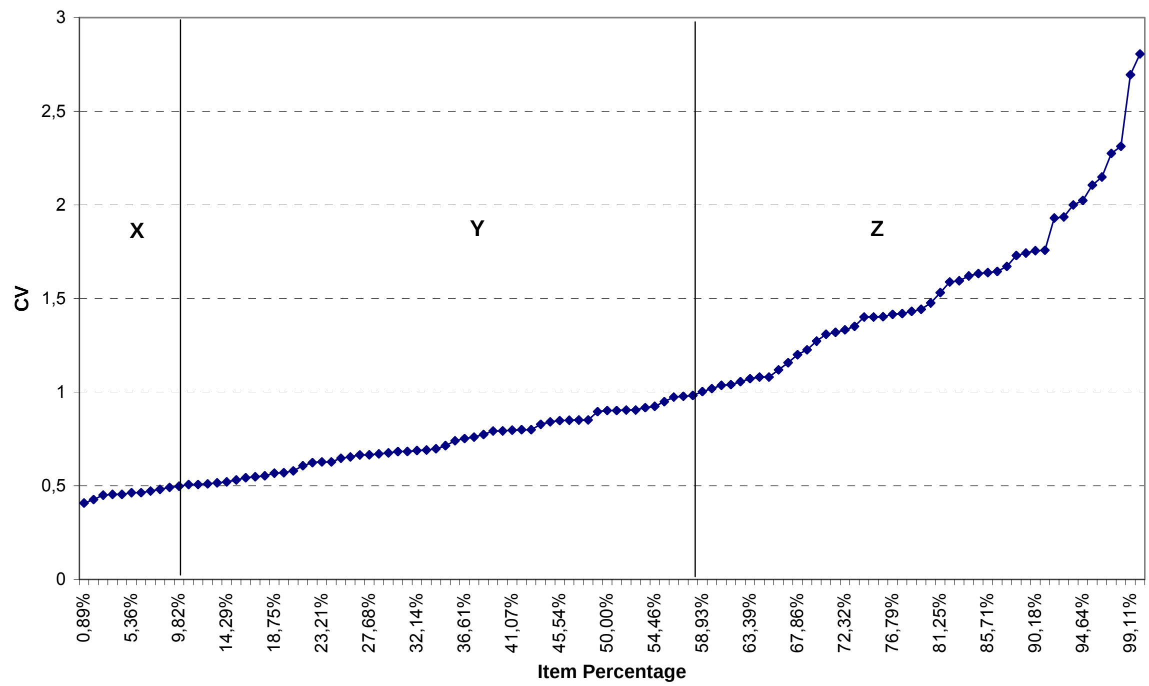

Figure 4. 8 XYZ Classification for RDC15

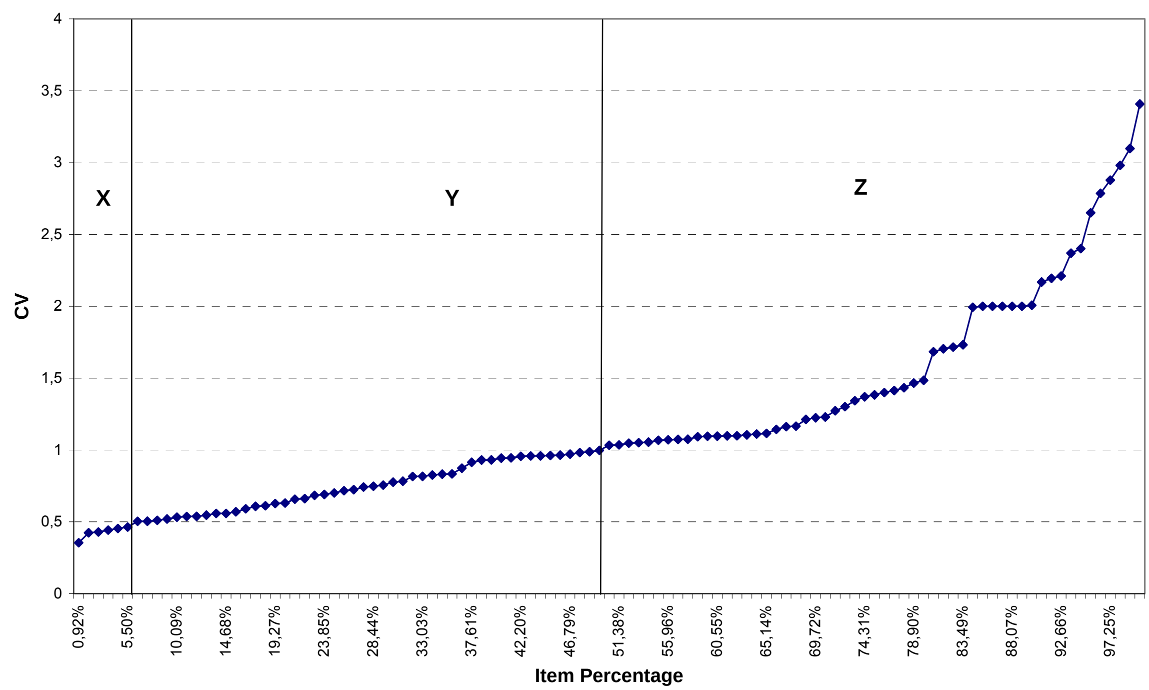

Figure 4. 9 XYZ Classification for RDC19

The percentage of items in each class for each distribution center is shown in Table 4.2 and the average percentage of items in each class for all the distribution centers is illustrated by Figure 4.10.

Table 4. 2 Percentage of Items in each Class for each Distribution Center

DC	X	Y	Z	Total
RDC1	16,04%	48,11%	35,85%	100,00%
RDC2	25,93%	40,74%	33,33%	100,00%
RDC3	18,58%	53,10%	28,32%	100,00%
RDC4	22,12%	56,73%	21,15%	100,00%
RDC5	19,09%	51,82%	29,09%	100,00%
RDC6	8,96%	51,49%	39,55%	100,00%
RDC7	11,40%	45,61%	42,98%	100,00%
RDC8	10,09%	48,62%	41,28%	100,00%
RDC9	29,63%	47,22%	23,15%	100,00%
RDC10	23,64%	45,45%	30,91%	100,00%
RDC11	17,43%	58,72%	23,85%	100,00%
RDC12	3,74%	57,94%	38,32%	100,00%
RDC13	19,47%	49,56%	30,97%	100,00%
RDC14	25,22%	47,83%	26,96%	100,00%
RDC15	9,82%	48,21%	41,96%	100,00%
RDC16	22,12%	35,58%	42,31%	100,00%
RDC17	21,60%	38,40%	40,00%	100,00%
RDC18	1,87%	45,79%	52,34%	100,00%
RDC19	5,50%	44,04%	50,46%	100,00%
LDC1	23,86%	65,91%	10,23%	100,00%
LDC2	31,40%	50,00%	18,60%	100,00%
LDC3	24,39%	52,44%	23,17%	100,00%
LDC4	37,04%	58,02%	4,94%	100,00%
LDC5	30,43%	51,09%	18,48%	100,00%

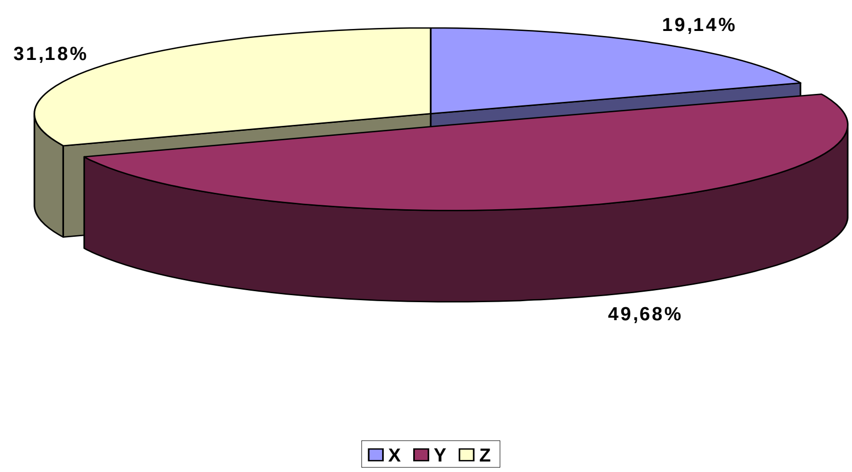

Figure 4. 10 Average Percentages of Items in each Class

ABC-XYZ Classification

To get more insight into the behavior and sensitivity of the demand pattern of each item, the items are clustered or grouped based on the combination of two classifications (ABC & XYZ classifications). Nine different categories (classes) of items are generated (XA, XB, XC, YA, YB, YC, ZA, ZB, and ZC). Figure 4.11 shows the percentage of items in the nine classes for each distribution center. Figure 4.12 illustrates the average percentage of items in each class for all the distribution centers.

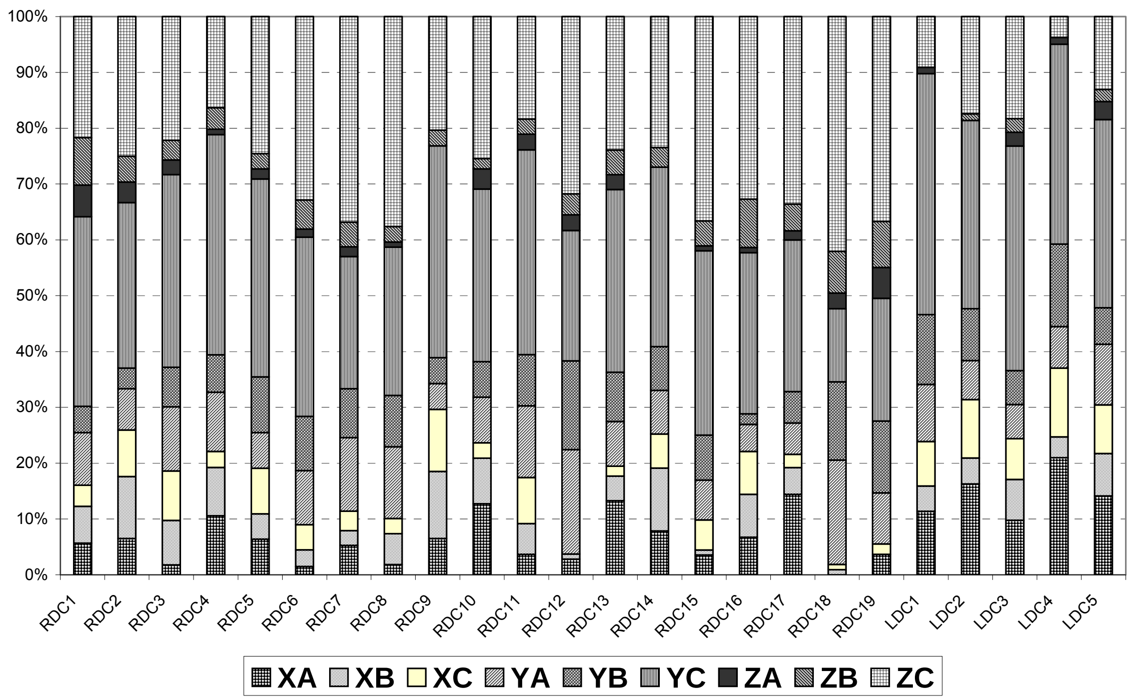

Figure 4. 11 Percentage of Items in each Class for each Distribution Center

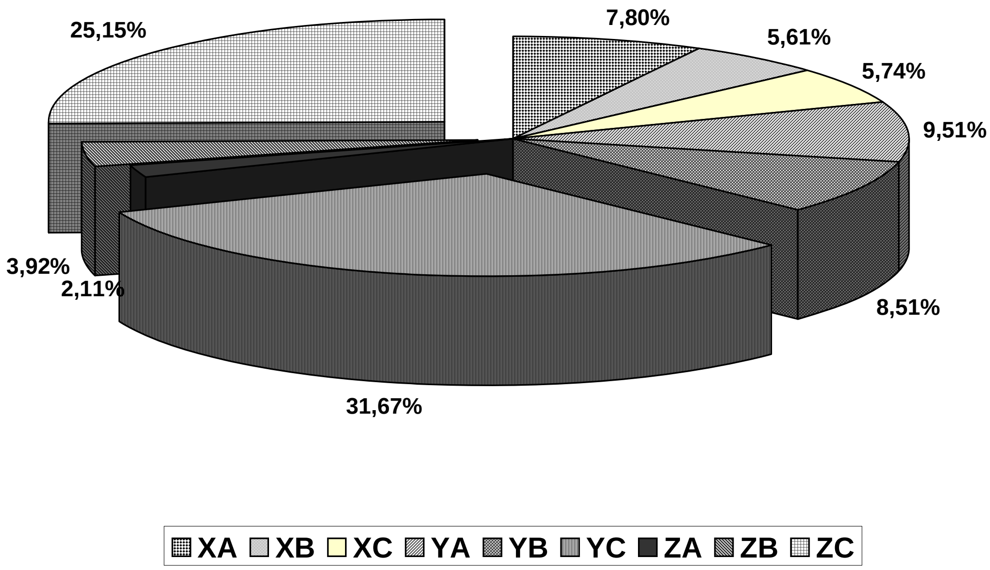

Figure 4. 12 Average Percentages of Items in each Class

Classification of items can also help to design more appropriate distribution strategies based on the objectives of supply chain decision makers. This fact has been proven by designing a lot of distribution strategies, using a two classification approach to achieve some goals and then comparing the results with those from some common strategies. As seen in the previous figures and tables, the item percentage of each class for each distribution center is completely different as compared with another distribution center for each of the three classification approaches (Table 4.1, 4.2, and Figure 4.11). Therefore, using a common distribution strategy for all the distribution centers based on the item classification is very difficult and hence the comparison is more complex. All of these difficulties and the design of the distribution strategies are described and discussed in the following sections.

4.2. Design of Uncoordinated Strategy Experiments

The design of each experiment strategy is constructed mainly based on the following four control parameters:

1. ABC classification
2. XYZ classification
3. Reorder point (fixed for each class or individual based on service level, **s**).
4. Maximum inventory level (order up-to-level, **S**).

For designing these experiments, some assumptions are considered:

- In all experiments the beginning inventory is assumed to be equal to the reorder point and the lead time is four days (LT = 4 Days).
- The inventory decisions are taken at the distribution centers.
- The continuous review installation stock (**s, S**) policy where **s** is the reorder point and ***S*** is the order up-to-level is used as inventory policy for all the experiments.
- The physical maximum capacity of inventory levels should be limited.
- The customer orders are filled completely.
- The filling of customer orders is based on a first-in-first-out (FIFO) rule.
- The number of distribution centers that have been considered is twenty four (DC's = 24).

Notation:

UCS-Expt: uncoordinated Strategy experiment

By using the above parameters and assumptions, ten experiments are constructed. The ten experiments are conducted by implementing the simulation model described in chapter three. To conduct the experiments by using the developed simulation model, the user should select the appropriate inventory policy and replenishment policy for each location in the network. In these experiments, the downstream locations were selected as the “distribution centres” for location type and “Allowed to keep inventory” was selected as the inventory policy. In this case, the distribution centres function as traditional stores and all the inventory decisions are taken at downstream locations (DCs). The less-than-truck-load (LTL) is also selected as the transportation strategy by selecting the (Only Demanded Order replenishment) as the replenishment policy. All of these strategies and policies could be selected through the input data mask parameters (Figure 3.5 and 3.19).

As mentioned above, the (s, S) system is used as a policy for controlling the inventory. It is interesting that (s, S) systems are frequently encountered in practice. However, the values of the control parameters are usually set in a rather arbitrary fashion. For B items (and even most A items) mathematical optimality does not make sense; instead, a fairly simple way of obtaining reasonable values of s and S is needed [SPP98]. Therefore, in the following experiments the values of s and S parameters for each item type are estimated by different ways to see the effect of selecting these control parameters on the performance of distribution strategies and also to see the benefit of using the simulation as a tool for estimating the optimal value of such parameters.

4.2.1. Experiment ABC– Item Strategy (without Safety Stock) - (UCS- Expt 1):

In this experiment only three of the above parameters have been considered. These parameters are the ABC classification, the reorder point and the maximum inventory level. The reorder point of each item is designed mainly based on common inventory policy (equal to the average demand during the lead time). The reorder point and the maximum inventory level of each item type are estimated by the following formulas:

Reorder Point (**s**) = Lead Time * Average Demand (Daily) (4.1)

Maximum Inventory Level (**S**) = Number of Days * Average Demand (Daily) (4.2)

The design of the experiment is summarized as shown in Table 4.3:

Table 4. 3 Reorder Point and Maximum Inventory Level for Each Item Class

ABC Classification	s (Days)	S (Days)
A	4	10
B	4	10
C	4	15

The above maximum inventory level is designed by taking the physical maximum capacity of the distribution centers in to consideration.

4.2.2. Experiment ABC-Item Strategy (with Safety Stock) – *(UCS-Expt 2):*

This experiment is designed in the same manner as the previous experiment except that the safety stock is considered in a different way. In this case the safety stock is equal to the fifty percentage of the demand during lead time [Bal04].

The reorder point of each item is designed as given by the following formula:

Reorder Point (**s**) = Lead Time * Average Demand (Daily) + Safety Stock

Reorder Point (**s**) = Lead Time * Average Demand (Daily) +
50% of [Lead Time * Average Demand (Daily)] (4.3)

Maximum inventory level (**S**) of each item is calculated by equation (4.2). The design of the experiment is summarized in Table 4.4:

Table 4. 4 Reorder Point and Maximum Inventory Level for Each Item Class

ABC Classification	s (Days)	S (Days)
A	6	10
B	6	10
C	6	15

4.2.3. Experiment ABC- Item Strategy (minimize transportation) – (UCS- Expt 3):

This strategy is designed mainly to get more savings on transportation costs. Due to attractive transportation cost rate with increased quantity, the shipment size of high consumption rate or important items (A items) is large and that for B- and C-items is lower. Most companies also keep a relatively large number of units of low consumption or important items (C items) in stock to minimize the amount of inconvenience that could be caused by a stockout of such insignificant parts [SPP98].

Based on all the mentioned rules, the reorder point and the maximum inventory level of each item are designed by selecting the appropriate number of days. It is clear that the difference in days between the s and S values determine the shipment size. Therefore, for example, to generate a large shipment size of type A-items, the difference between the s and S in days should be big. For keeping a large number of the type C-items at the distribution centers, the number of days for estimating the reorder point of such item type should be high.

The reorder point and maximum inventory level of each item are estimated by the general equation (4.4). Table 4.5 illustrates the number of days given for each parameter.

$$\mathbf{s} \text{ or } \mathbf{S} = \text{Number of Days} * \text{Average Demand (Daily)} \qquad (4.4)$$

Table 4. 5 Reorder Point and Maximum Inventory Level for Each Item Class

ABC Classification	s (Days)	S (Days)
A	4	10
B	6	10
C	10	15

4.2.4. Experiment C- Item Allocation Strategy- (UCS- Expt 4):

The allocation of item inventory is one of the distribution strategies which has been widely used in the literatures and practice to minimize the systemwide cost especially when the holding cost is very high [NT01], [CM04]. Additionally, other factors, such as the emergency of items and the satisfaction of customers, should be considered. All of these savings and the factors will be realised by this experiment. The logic of this strategy is to keep items with a very low demand or slow-moving items (C) at upstream location (Warehouse) and items with a very high demand or fast-moving items or more demanded items (A and B) close to the customer, at the lowest downstream location (Distribution Centre) to minimize the inventory and transportation costs. By using the equation (4.4) the reorder point and maximum level of each item are constructed. To implement this strategy, the reorder point (s) for each type C-item is estimated as zero days. Table 4.6 shows the design of the strategy:

Table 4. 6 Reorder Point and Maximum Inventory Level for Each Item Class

ABC Classification	s (Days)	S (Days)
A	4	10
B	4	10
C	0	15

4.2.5. Experiment XYZ-Item Strategy - (UCS- Expt 5):

The uncertainty in the demand pattern of multi items significantly complicates the controlling of the inventory and the designing of an appropriate distribution strategy. Most organizations make an appropriate reallocation of safety stock to meet the unexpected fluctuations in demand which lead to a significant improvement in the customer services. More safety stocks should be given for items with high variability demand and vice versa. The two parameters (**s** & **S**) are designed by taking the uncertainty into account and by calculating using the same equation (4.4). For example, the value of the reorder point (s) for the high variability items (Z) is the biggest. Table 4.7 shows the estimation of these two parameters (**s** & **S**).

Table 4. 7 Reorder Point and Maximum Inventory Level for Each Item Class

XYZ Classification	s (Days)	S (Days)
X	4	10
Y	6	10
Z	10	15

4.2.6. Experiment Z- Item Allocation Strategy- (UCS- Expt 6):

In this experiment, the logic of the strategy is to keep the items with high variability demand (Z Item), that are very difficult to be forecasted, at the upstream location (Warehouse) and the items with low variability demand, that can be forecasted with accuracy, close to the customer at lowest downstream location (Distribution Centre).Therefore, the reorder point for each type Z-item is estimated to be zero days. The reorder point and maximum inventory level of each item type are estimated by equation (4.4).

The strategy is designed as given in Table 4.8.

Table 4. 8 Reorder Point and Maximum Inventory Level for Each Item Class

XYZ Classification	s (Days)	S (Days)
X	4	10
Y	4	10
Z	0	15

4.2.7. Experiment ABC- XYZ - Combination Strategy- (UCS- Expt 7):

In this experiment, nine classes of items are generated based on the ABC-XYZ classification. The reorder point of each item is constructed based on these nine categories and by using equation (4.4). The mechanism of this strategy is to give more safety stock for a very important item with high variability demand (YA, ZA, and ZB) and less safety stocks for less important item with high demand variability (YC and ZC). For example, the value of s for the type ZA-item is the largest and for the type ZC-item is the smallest.

The reorder point is given by Table 4.9:

Table 4. 9 Reorder Point for Each Combined Item Class

	A	B	C
X	4	4	4
Y	5	4	2
Z	6	5	1

The maximum inventory level is given in Table 4.10:

Table 4. 10 Maximum Inventory Level for Each Combined Item Class

	A	B	C
X	10	10	15
Y	10	10	15
Z	10	10	15

Note: all the values in the tables are in days.

4.2.8. Experiment ABC- XYZ – Combination Strategy (MIL) - (UCS-Expt 8):

This experiment is designed by the same method as that used in the previous combination experiment. The only difference is in the maximum level estimation. Here the maximum level of less important items (B and C) is reduced to minimize the shipment size and the average ending inventory of these items. For example, in all the previous experiments the value of the maximum inventory level (S) of the type C-items is equal to fifteen days, and in this strategy it is only eight days.
The maximum inventory level is given by Table 4.11:

Table 4. 11 Maximum Inventory Level for Each Combined Item Class

	A	B	C
X	10	8	8
Y	10	8	8
Z	10	8	8

Note: all the values in the tables are in days.

4.2.9. Experiment CSL (80%) ABC Item Strategy- (UCS- Expt 9):

As the variability of demand grows the required level of safety stock inventory increases. The appropriate level of safety stock inventory is determined by the following two factors [CM04]:

1. The uncertainty of both demand and supply
2. The desired level of product availability

One of the measures of item availability is Cycle Service Level (CSL).
Cycle Service Level (CSL) is the fraction of replenishment cycles that end with all the customer demand being met. *A replenishment cycle* is the interval between two successive replenishment deliveries. Therefore, CSL is equal to the probability of not having a stockout in a replenishment cycle. In this case safety stock (safety

inventory) is determined based on desired Cycle Service Level (CSL) of decision makers. The reorder point (s) for each item will be calculated based on this result.

The procedure can be described as follows:

Observe that a stockout occurs in a cycle if demand during the lead time is larger than the ROP (**s**). Thus, identify the safety inventory SS such that the following is true:

CSL= probability (demand during lead time ≤ $D_L + SS$)

- If demand during lead time is normally distributed with a mean of D_L and a standard deviation of σ_L where,

  $D_L = D \times L$ and $\sigma_L = \sqrt{L} \times \sigma_D$, so that

  $$F(D_L + SS, D_L, \sigma_L) = CSL \qquad (4.5)$$

- By using the definition of the inverse normal, the equation can be derived

  $$D_L + SS = F^{-1}(CSL, D_L, \sigma_L), \text{ or } SS = F^{-1}(CSL, D_L, \sigma_L) - D_L \qquad (4.6)$$

- By using the definition of standard normal distribution, its inverse can be modified as follows:

  $$SS = F_S^{-1}(CSL) \times \sigma_L \qquad (4.7)$$

Finally, the reorder point (s) can be calculated by

$$s = D_L + SS \qquad (4.8)$$

where:

$CSL =$ Desired cycle service level,

$D =$ Average demand,

$\sigma_D =$ Standard deviation of demand,

$D_L =$ Mean demand during lead time,

$\sigma_L =$ Standard deviation of demand during lead time,

$L =$ Average lead time for replenishment

$SS =$ Safety stock

$s =$ Reorder point

This procedure has been applied under an important assumption that the continuous review replenishment (ROP, Q) policy is implemented. In this thesis the procedure is used under (s, S) replenishment policy and with different distributions of the demand and lead time.

In this experiment, the reorder point of each item is designed to achieve a CSL of 80%. The maximum inventory level of each item is calculated as in the previous experiments. The reorder point designed of each item is calculated by equation (4.8) and the maximum inventory level of each class is calculated by equation (4.4). Table 4.12 shows the desired Cycle Service Level (CSL) and the maximum inventory level for each item class:

Table 4. 12 Cycle Service Level and Maximum Inventory Level for Each Item Class

ABC Classification	CSL(%)	S (Days)
A	80%	10
B	80%	10
C	80%	15

4.2.10. Experiment CSL (90%) ABC Item Strategy- (UCS-Expt 10):

The reorder point and the maximum inventory of each item are estimated using the same procedures in the previous strategy; here the reorder point of each item is designed to achieve a CSL of 90 percent.

The designed parameters of this experiment are shown in Table 4.13.

Table 4. 13 Cycle Service Level and Maximum Inventory Level for Each Item Class

ABC Classification	CSL(%)	S (Days)
A	90%	10
B	90%	10
C	90%	15

The design of all the ten strategies will be summarized in the following tables:

Table 4. 14 Experimental Index (1)

Expt-Name	s (Days)						S (Days)					
	A	B	C	X	Y	Z	A	B	C	X	Y	Z
UCS- Expt 1	4	4	4	-	-	-	10	10	15	-	-	-
UCS- Expt 2	6	6	6	-	-	-	10	10	15	-	-	-
UCS- Expt 3	4	6	10	-	-	-	10	10	15	-	-	-
UCS- Expt 4	4	4	0	-	-	-	10	10	15	-	-	-
UCS- Expt 5	-	-	-	4	6	10	-	-	-	10	10	15
UCS- Expt 6	-	-	-	4	4	0	-	-	-	10	10	15

Table 4. 15 Experimental Index (2)

Expt-Name	CSL (%)						S (Days)					
	A	B	C	X	Y	Z	A	B	C	X	Y	Z
UCS- Expt 9	80%	80%	80%	-	-	-	10	10	15	-	-	-
UCS- Expt 10	90%	90%	90%	-	-	-	10	10	15	-	-	-

Table 4. 16 Experimental Index (3)

Expt-Name	s (Days)									S (Days)								
	XA	XB	XC	YA	YB	YC	ZA	ZB	ZC	XA	XB	XC	YA	YB	YC	ZA	ZB	ZC
UCS- Expt 7	4	4	4	5	4	2	6	5	1	10	10	15	10	10	15	10	10	15
UCS- Expt 8	4	4	4	5	4	2	6	5	1	10	8	8	10	8	8	10	8	8

4.3. Performance Measures:

To compare the experiments and to see how significantly each the strategies affects the system performance, six measures of performance are selected to provide measures of the logistics costs and customer responsiveness/ backorders. These measures are most commonly used to measure the supply chain performance, and are described in the following section:

In the following sections the following notations are used:

$i =$ Distribution centre i.

$I =$ Total number of items

$j =$ Warehouse j

$TC =$ Transportation cost for one year

$n =$ Total number of distribution centres

$W =$ Total number of warehouses

$s =$ A stockout item

$S =$ Total number of stockout items

$sc =$ A stockout item in a class

$C =$ Total number of stockout items in a class

4.3.1. Total Transportation Cost (TTC):

This is equal to the sum of the transportation costs for one year between each warehouse and distribution centre (Inbound Transportation cost). The required data for calculating TTC is collected from the financial summary report (Table 3.10 and Table 3.14).

$$\textbf{TTC} = \sum_{j=1}^{W}\sum_{i=1}^{n} TC_{ji}\ , \tag{4.9}$$

Where TC_{ji} is the transportation cost between warehouse j and distribution centre i.

4.3.2. Total Inventory Holding Cost (TIHC):

This is equal to the sum of the inventory holding costs for one year for all distribution centres. It is calculated using the average daily ending inventory (pallet unit). To calculate the average daily ending inventory, some data should be collected from aggregated inventory investment report (Table 3.12).

$$\text{TIHC} = \sum_{i=1}^{n} IHC_i \tag{4.10}$$

$IHC =$ Inventory holding cost for one year.

4.3.3. Total Logistics Cost (TLC):

This is equal to the sum of the transportation cost and inventory holding cost.

$$\text{TLC} = \text{TTC} + \text{TIHC} \tag{4.11}$$

4.3.4. Item Fill Rate Measures:

This is the fraction of item demand that is satisfied from item stock.

1. Item Fill Rate (IFR) = 1 - (total number of orders of an item not satisfied /total number of orders of an item) (4.12)
2. Average Item Fill Rate of each DC (AIFR) = $\dfrac{\sum_{s=1}^{S}(IFR)_s}{S}$ (4.13)
3. Average Item Fill Rate of each Class (AIFRC) = $\dfrac{\sum_{sc=1}^{C}(IFR)_{sc}}{C}$ (4.14)
4. Average of Average Item Fill Rate of all DCs (AAIFR) = $\dfrac{\sum_{i=1}^{n}(AIFR)_i}{n}$ (4.15)

4.3.5. Order Lines Fill Rate Measures:

The order line fill rate is the fraction of order lines that is satisfied immediately from item stock.

Order Lines Fill Rate of each DC (OLFR):

$$OLFR = 1 - \frac{Total\ number\ of\ order\ lines\ not\ satisfied}{Total\ number\ of\ order\ lines} \tag{4.16}$$

Average of Order Lines Fill Rate of all DCs (AOLFR):

$$AOLFR = \frac{Total\ order\ lines\ fill\ rate\ of\ DCs}{Total\ number\ of\ DCs}$$

$$AOLFR = \frac{\sum_{i=1}^{n} (OLFR)_i}{n} \tag{4.17}$$

For calculating OLFR and IFR, some data from inventory tracing reports should be collected (Table 3.11).

4.3.6. Order Fill Rate Measures:

The order fill rate is the fraction of orders that are filled completely from available item stock. This measure is very important when the customer orders must be filled completely.

The Order Fill Rate of each DC (OFR):

$$OFR = 1 - \frac{Total\ number\ of\ order\ not\ satisfied}{Total\ number\ of\ orders} \tag{4.18}$$

Average of Order Fill Rate (AOFR):

$$AOFR = \frac{Total\ order\ \ fill\ rate\ of\ \ DCs}{Total\ number\ of\ \ DCs}$$

$$AOFR = \frac{\sum_{i=1}^{n} OFR_i}{n} \qquad (4.19)$$

The required data for calculating OFR is gathered from service order degree reports (Table 3.16).

Some costs (Pickup, Order, unloading, and loading) are negligible compared with transportation or holding costs, so for the sake of simplicity they are not taken into account.

4.4. Experimental Simulation Results and Analysis

Simulation results are collected after running the simulation model for one year. Once the model has been simulated, many detailed output reports on every aspect of the measures of performance are generated by the simulation model (see chapter three). The simulation results (measures of performance), analysis of results and some findings will be shown in the following section.

The summary of measures of performance for each strategy are ranked in ascending order based on the average order fill rate (AOFR) and presented in Table 4.17 and Figure 4.13. Figure 4.14 shows the percentage increase in the total logistics costs for each strategy as compared with the experiment C-Item Allocation Strategy. This strategy (UCS- Expt 4) has been considered as a base experiment because it has the minimum total logistics costs.

Table 4. 17 Measures of Performance for Each Strategy Based on Ascending Order of Average Order Fill Rate

Experiments	TTC	TIHC	TLC	AOLFR	AOFR
UCS-Expt 4*	$8.109.584,95	$205.694,79	$8.315.279,74	86,49%	10,10%
UCS-Expt 6	$8.116.662,30	$233.927,36	$8.350.589,66	88,91%	12,98%
UCS-Expt 8	$8.146.816,06	$238.005,21	$8.384.821,27	92,06%	32,76%
UCS-Expt 7	$8.124.646,65	$266.363,19	$8.391.009,84	95,04%	43,23%
UCS-Expt 1	$8.114.944,57	$276.000,10	$8.390.944,67	96,44%	61,06%
UCS-Expt 5	$8.139.476,97	$340.781,80	$8.480.258,77	97,44%	71,46%
UCS-Expt 3	$8.125.338,06	$344.206,49	$8.469.544,55	98,17%	77,19%
UCS-Expt 9	$8.139.772,59	$317.015,50	$8.456.788,09	98,23%	78,45%
UCS-Expt 2	$8.149.488,60	$321.158,15	$8.470.646,75	98,68%	83,65%
UCS-Expt 10	$8.150.344,06	$340.914,26	$8.491.258,32	98,72%	84,08%

* Base Experiment

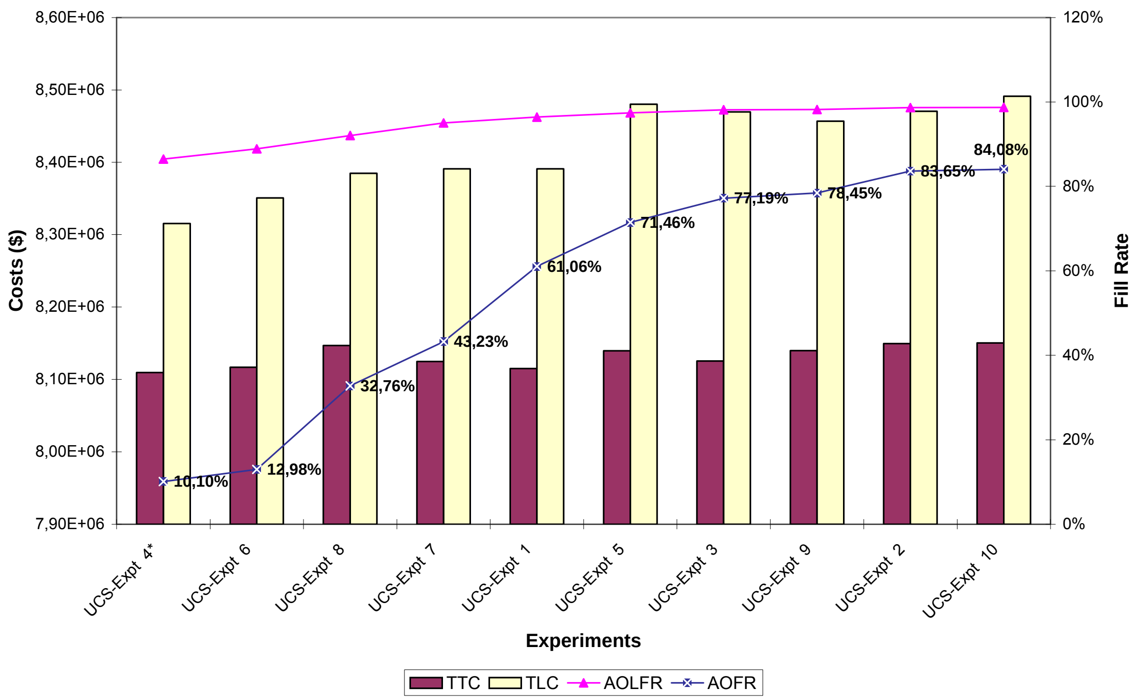

Figure 4. 13 Measures of Performance for Each Strategy Based on Ascending Order of Average Order Fill Rate

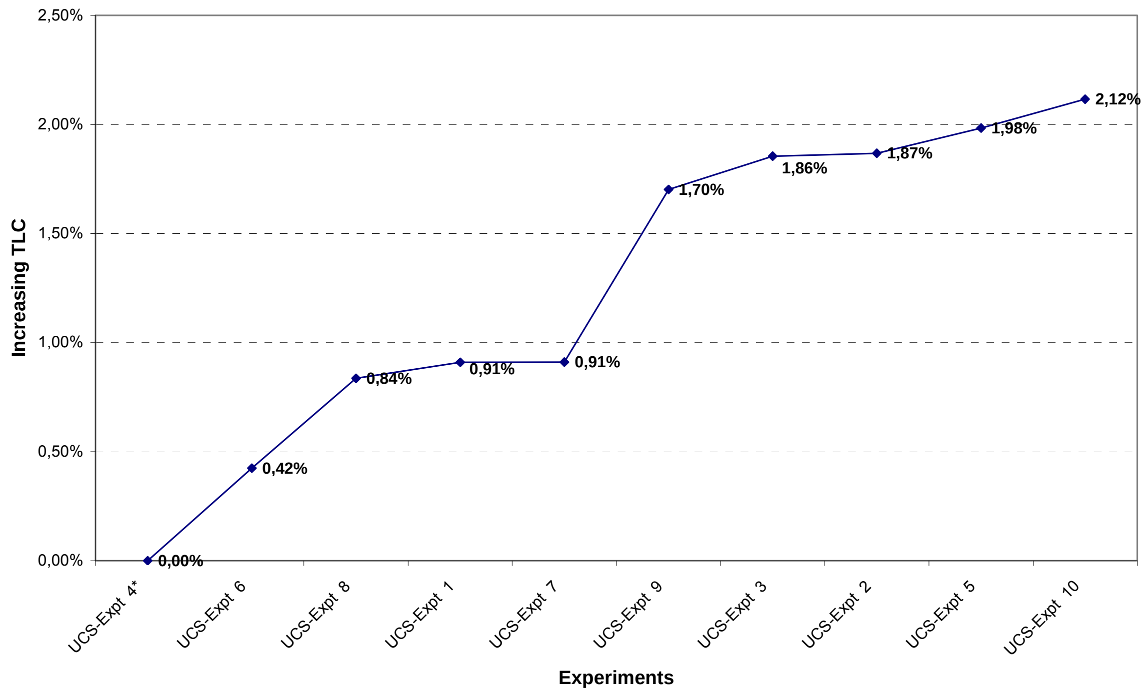

Figure 4. 14 Percentage Increase of the Total Logistics Costs

4.4.1. Logistics Costs Analysis:

The following analysis can be made based on Table 4.17 and Figure 4.13:

1. In the case minimizing of the total logistic cost is the main objective and if the item fill rate is not to be less than 85% and that it is not used as a measure of performance (especially when the holding inventory cost is very high and the customer orders are partially filled) then it is recommended that allocation strategies are used.
2. From the results, the C-Item allocation strategy performs better than the Z-Item allocation strategy and the reduction of the total logistic cost is about more than 0.5% but the Z-Item has improved the fill rate by more than 2%. This can be explained by the fact that the keeping of slow-moving items (C) at upstream location produces less transportation between the upstream and downstream locations as compared with keeping the Z items at

upstream locations. Keeping the Z items at upstream locations produces more transportation because some of Z items are A items (fast-moving items) which are more demanded items. Also, keeping slow-moving items (C) at upstream locations produces less ending inventory at the downstream locations as compared with keeping the Z items at upstream locations. This is due to the difference in the item percentage of each class. The average item percentage of C items class is equal to 62.55% and the average item percentage of the Z items class is equal to 31.18% (Table 4.1, Table 4.2, Figure 4.5, and Figure 4.10). Furthermore, the significant difference in item percentages justifies, in general, the low average order fill rate for both strategies.

3. In the case where the inventory levels are adjusted to achieve an item fill rate of more than 90%, 70% order fill rate and transportation costs have the first priority, it is recommended to use experiment ABC-item strategy. It performs better than the others with a saving in transportation cost of 0.30%.
4. In the case where the order fill rate (more than 80%) has the first priority, it is recommended to use the common strategies, especially the CLS-Strategies. These strategies are more sensitive to item variability and therefore they can produce high service levels with no considerable increase in the total logistics costs.
5. In most cases, as the order fill rate is increased the total logistics costs are increased.
6. On the other hand, a high average daily ending inventory (TIHC) cannot be correlated with the high service levels (AOLFR & AOFR) in all the strategies. For example, the experiment CSL (90%) ABC Item strategy (UCS-Expt 10) and the experiment XYZ-Item strategy (UCS- Expt 5) have approximately the same total inventory holding cost (TIHC), but the AOFR of the UCS-Expt 10 strategy is approximately 13% higher than that in the UCS- Expt 5 strategy.

7. As seen in Figure 4.14, the optimal strategy (Experiment CSL (90%) ABC Item Strategy) increases the total logistics cost by only approximately 2% as compared with the experiment C Item Allocation strategy (UCS- Expt 4), while at the same time it is approximately 74% higher in AOFR as compared to that in the UCS- Expt 4 strategy.
8. Figure 4.14 shows that some strategies could have the same percentage of increase in the total logistics costs with a significant different in the AOFR. For example, the experiment ABC– Item strategy (without Safety Stock) - (UCS- Expt 1) and the experiment ABC- XYZ – Combination strategy- (UCS- Expt 7), have approximately the same total logistics cost but the AOFR of the UCS- Expt 1 strategy is approximately 18% higher than that in the UCS- Expt 7 strategy. This can be explained by the fact that in the UCS- Expt 7 strategy the less important items with high demand variability (YC and ZC) have given less safety stock. These items present on average approximately 57% of the total items (Figure 4.12). The high percentage of these items justifies the low value of AOFR of this strategy and also the small ending inventory. Furthermore, the total transportation cost of the UCS- Expt 7 strategy is higher than the total transportation cost of the UCS- Expt 1 strategy. This can also be justified by the fact that when these items (YC and ZC), have less safety stock results in less reorder point (s) which in turn increases the shipment size of those items. Increasing the shipment size increases the transportation cost.
9. Furthermore, as seen in Figure 4.14, the percentage of increasing the total logistics costs by each strategy is very small. This can be justified by the sharing of transportation costs in the total logistics costs, as shown in Figure 4.15.

10. The cost categories shares of the logistics costs for all strategies are presented in Figure 4.15. The bigger share on average for all strategies represents transportation costs (96%), whereas average inventory costs represent only a small portion of logistics costs (4%).

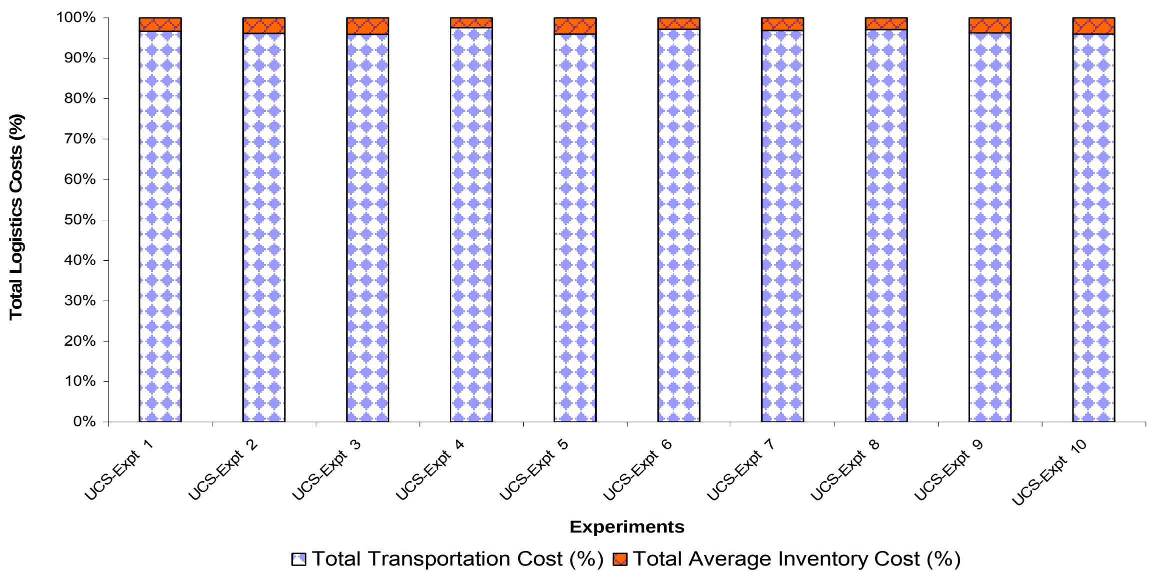

Figure 4. 15 Costs Categories Shares Regarding Logistics Costs for All Strategies

Based on Table 4.17, four strategies with safety stock policy are selected to be discussed in more detail (for each distribution center) in order to get a better insight into the sensitivity of the item classification to these strategies. These strategies are as follows:

1. Experiment ABC–Item Strategy (without Safety Stock) as a base experiment (UCS-Expt 1*).
2. Experiment ABC-Item Strategy (with Safety Stock) – (UCS-Expt 2).
3. Experiment CSL (80%) ABC Item Strategy – (UCS-Expt 9).
4. Experiment CSL (90%) ABC Item Strategy – (UCS-Expt 10).

The measures of performance of all selected strategies of only nineteen regional distribution centres (RDC's = 19) are selected and presented in Figure 4.16, Figure 4.17 and Figure 4.18.

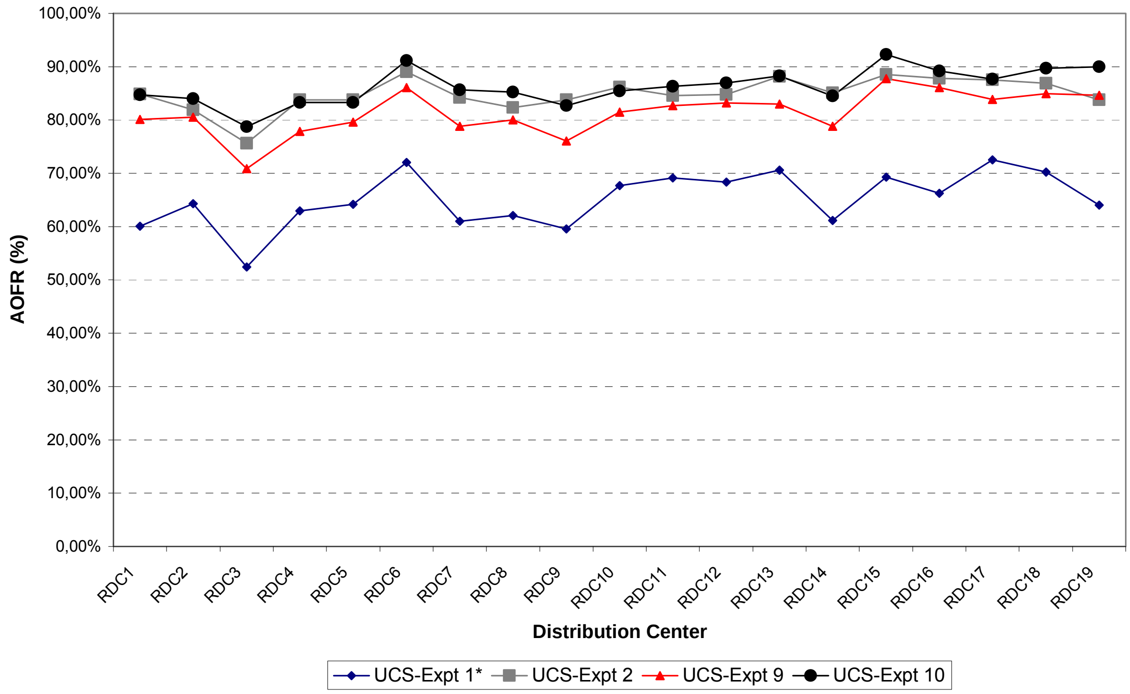

Figure 4. 16 Average Order Fill Rate of Selected Strategies for Each Distribution Center

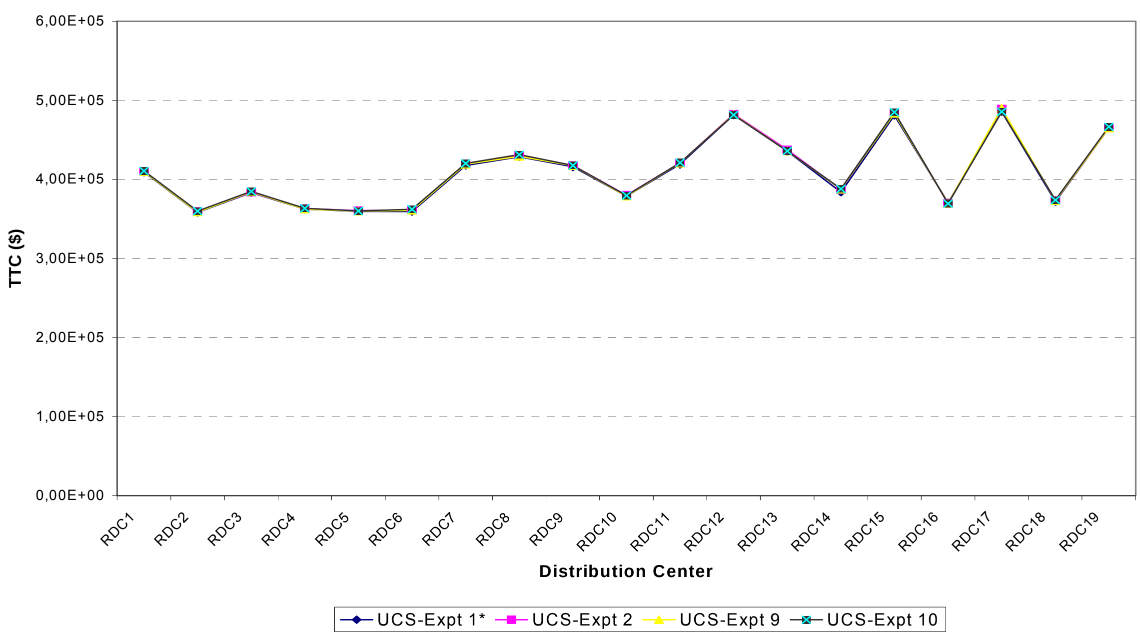

Figure 4. 17 Total Transportation Costs of Selected Strategies for Each Distribution Center

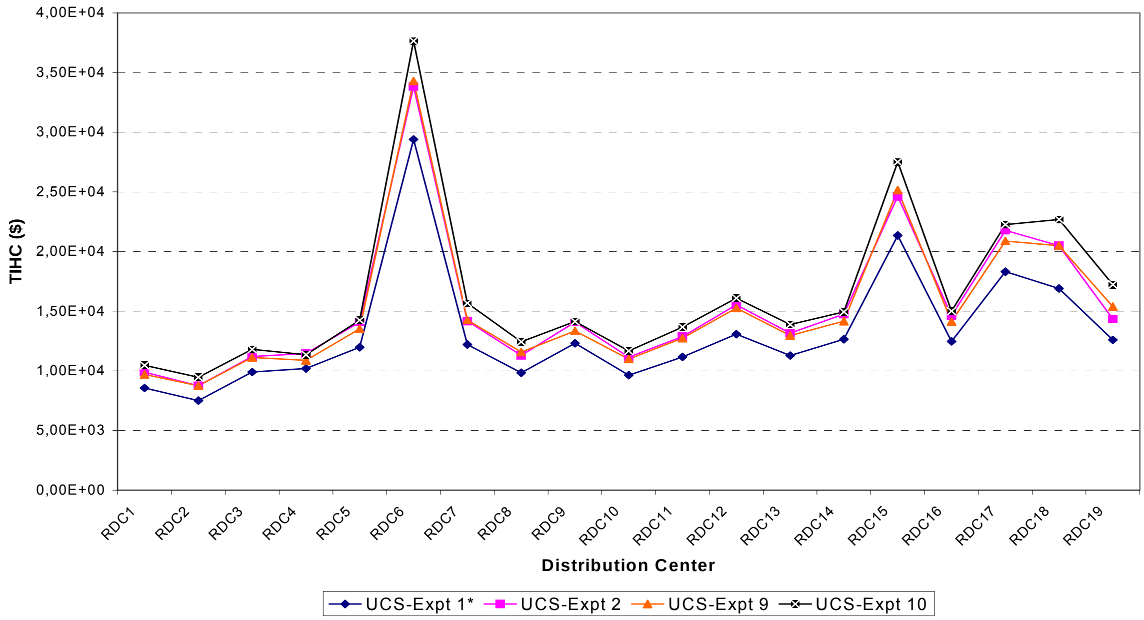

Figure 4. 18 Total Inventory Holding Cost of Selected Strategies for Each Distribution Center

* Base experiment

In this analysis the base experiment (without Safety Stock) is also assumed to be improved together with the other three strategies. The following can be observed from the previous figures and tables:

- Experiment ABC-Item Strategy (with Safety Stock) performs better than the others as in all measures of performance when the percentage of items in X-class is greater than the percentage of items in Z-class, as is the case in the regional distribution center RDC9 (Table 4.2). Additionally, this distribution center has the lowest average coefficient of variation per item (Figure 3.16). Therefore, it is recommended to use this strategy when the variation in demand in most of the items is low and the distribution of demand can be fitted to normal distribution (Table 3.18).
- It is recommended to use the average coefficient of variation per item, rather than to use the coefficient of variation based on aggregate demand, to get a better insight into the data sensitivity and item demand variability for

designing appropriate distribution strategy. As an example, two regional distribution centers RDC9 and DC17 are selected. The distributions of the aggregated daily average demand of both distribution centers are fitted to give a normal distribution. The CV (coefficient of variation) of the aggregated demand and average of the CV per item of both are given by the following table:

Table 4. 18 Average of CV per item and CV for the Two Regional distribution centers

DC	Average of CV per Item	CV
RDC9	0,81	0,40
RDC17	0,91	0,36

- From Table 4.18, RDC17 has less variability if the CV is taken as the criteria of demand variability. But if the average of CV per item is taken as the criteria it is clear that the demand variability of RDC9 is more stationary than the demand variability of RDC17. Therefore, more attention should be given to both coefficients in order to understand the behavior of demand variability.

- Experiment CSL (90%) ABC Item Strategy performs better than the others in terms of all measures of performance when the percentage of items in Z-class is greater than the percentage of items in X-class, for example for RDC15 (Table 4.2). It is, therefore, recommended to use this strategy when the variability in demand in most of the items is very high, as it is more sensitive to variability in demand for each item.
- Additionally, by using CSL equations (equation 4.7 and 4.8) to design the reorder point of items when the distribution center has a high percentage of items with a high variation of demand (Y & Z items) the CSL equations can achieve more than the desirable service level. For example in RDC15, CSL

equations achieve more than the desirable level in both of the two CSL strategies (80% & 90%). The order fill rate of this distribution center in both strategies is equal to 87.71% and 92.28% respectively (Figure 4.16). This is due to the high percentage of ZC-items (37%) and YC-items (33%) in this RDC (Figure 4.11). This means the percentage of items with high variation of demand represent more than 70% of the total items (Table 4.2, Figure 4.11).

- From the results, the CSL equations have been proven to be a good estimation for the reorder point even when the (s, S) inventory systems are used and the distribution of the demand and the lead are not normally distributed.

4.4.2. Fill Rate Analysis:

From the simulation results, the order fill rate (OFR) of each DC for all experiments, for the nineteen important distribution centers (RDCs) is calculated and illustrated in Figure 4.19.

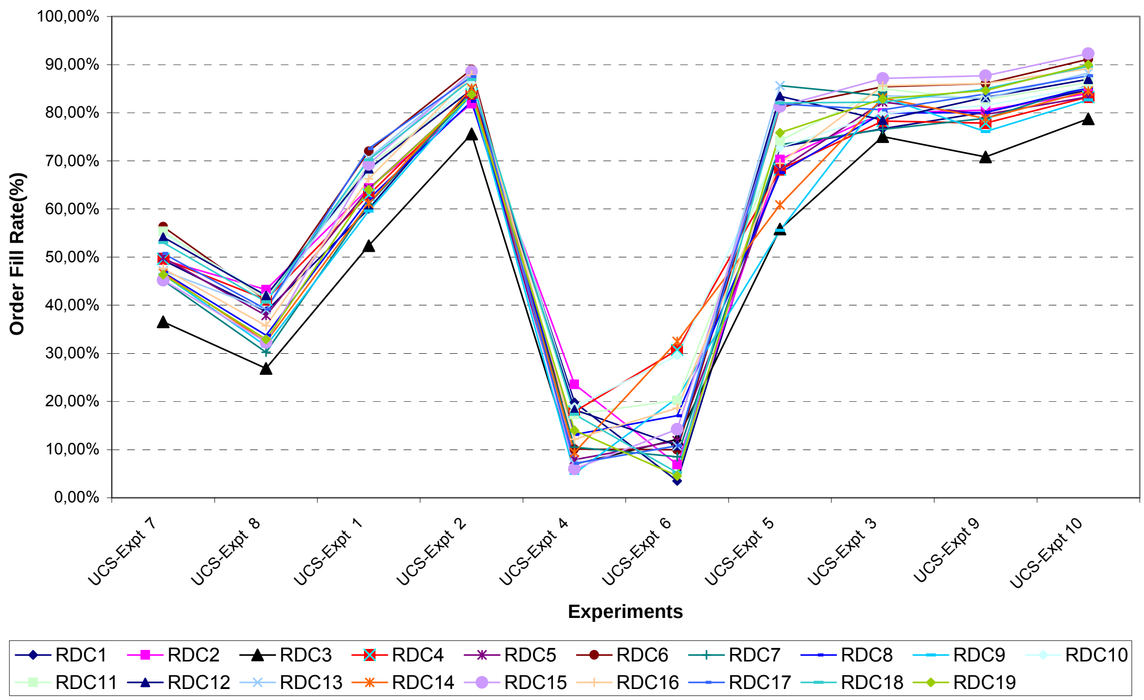

Figure 4. 19 Order Fill Rate of Each Distribution Center for Each Strategy

Analyses of these results were carried out and some findings are explained below:

- Some distribution centers perform very low order fill rates (OFR) in most of the experiments (Figure 4.19). The reason behind this is that such distribution centers have very high variations in demand rate especially during the lead time period (for example, RDC3).
- To explain this, the average item fill rates for each combined item class (AIFRC) and for each strategy of RDC3 are estimated. Figure 4.20 shows the AIFRC of only six strategies (experiments).
- Another reason for low item fill rate of RDC3 is the lack of classification of items. Figure 4.20 shows the problem with XB & XC items. These items are frequent items (with low coefficient of variation), of low demand. Therefore, they should be treated as emergency items or the reorder point of these items should be redesigned. Another optimal solution of this problem is to

make new appropriate classification, as will be discussed in the next chapters.

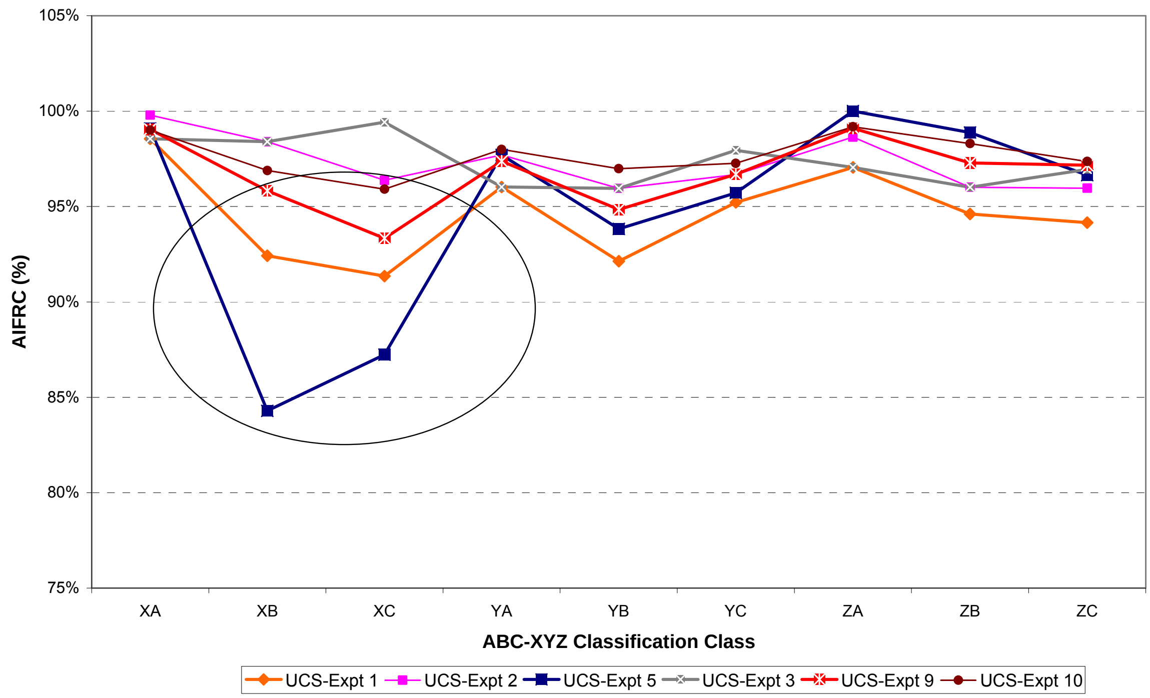

Figure 4. 20 Average Item Fill Rates of Each Combined Item Class (RDC3)

In order to give a greater explanation of the problem (lack of classification approach), three large distribution centers are selected. These are: RDC6, RDC15, and RDC19 respectively. The average item fill rate of each combined item class (AIFRC) for each strategy is calculated and illustrated in Figures 4.21, 4.22 and 4.23.

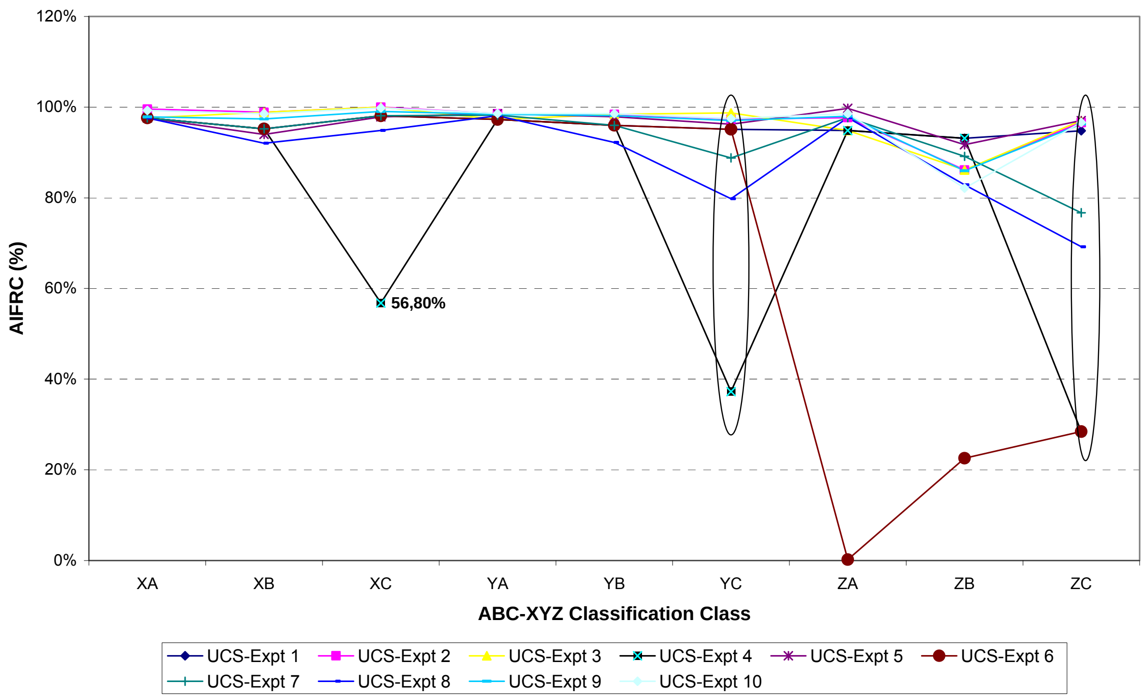

Figure 4. 21 Average Item Fill Rate of Each Combined Item Class (RDC6)

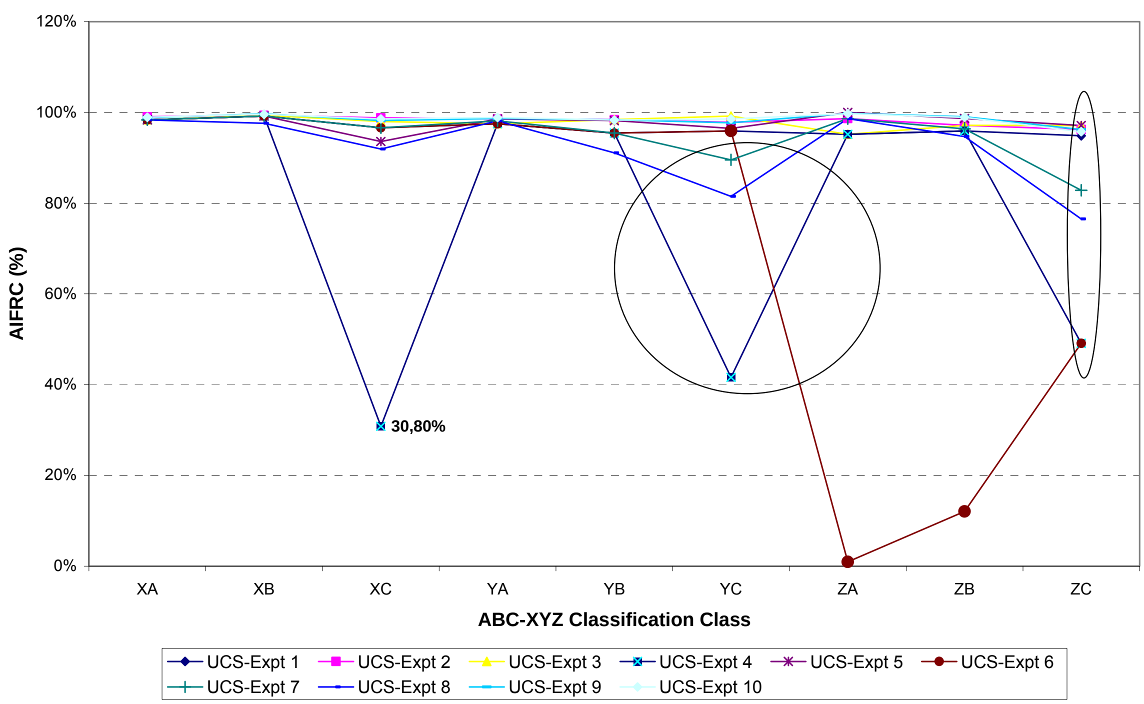

Figure 4. 22 Average Item Fill Rate of Each Combined Item Class (RDC15)

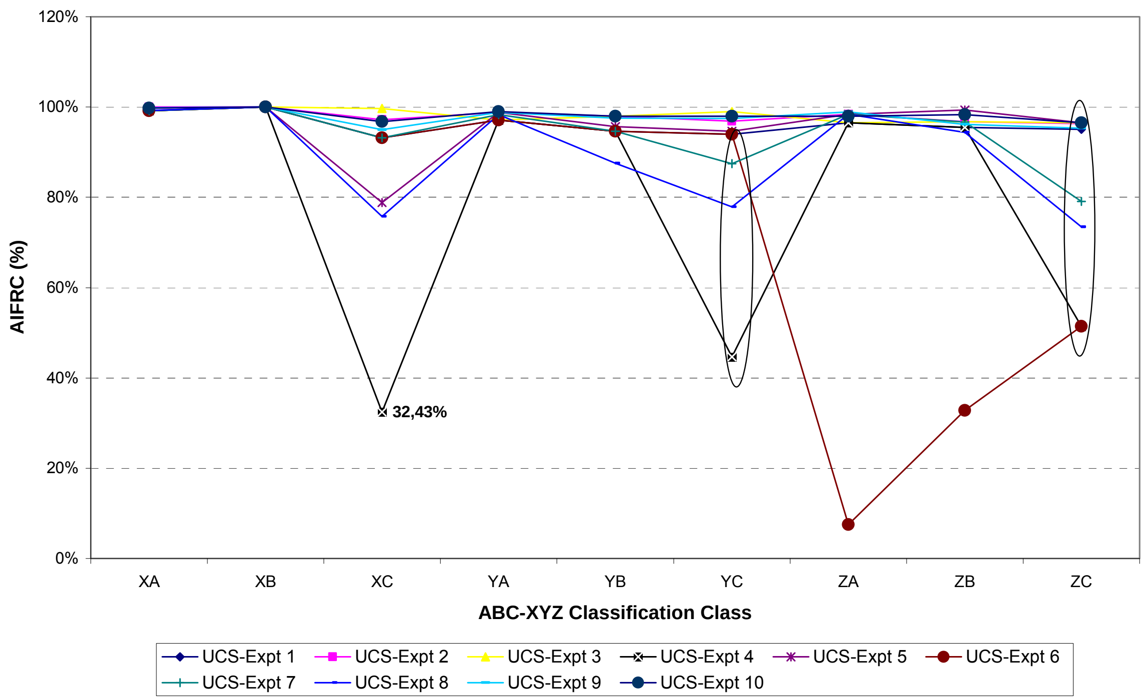

Figure 4. 23 Average Item Fill Rate of Each Combined Item Class (RDC19)

- Figures 4.21, 4.22, and 4.23 show that, the average item fill rate of combined item class (ZA, ZB, and ZC) is very low under the experiment Z - Item Allocation strategy (UCS- Expt 6) and the average item fill rate of the combined item class (XC, YC, and ZC) is very low under experiment C Item Allocation strategy (UCS- Expt 4). It is clear because the reorder point (s) of all these item types is equal to zero and all of these item types were kept at the upstream locations. Therefore, these strategies produce very low order fill rate (OFR) as compared with others.

- Moreover, from the previous figures, the effect of each strategy on the distribution centers seems to be the same. This means that, the conclusions from these strategies could be more general and suitable for a more general structure of supply chain (more robustness).

The percentage of items in each class plays an important role in designing distribution strategies to optimize system performances. For example, the percentage of C-class items is the highest percentage compared to the other classes, and difference in percentage between the classes also varies for the different distribution centers (Table 4.1, Figure 4.5).

For more explanation of the lack of classification problem, the average item fill rate of the combined item class (XC) for the all three distribution centers are compared. It is clear from the above three figures that, the average item fill rate of XC class of the RDC6 is the highest with a significant difference in the percentages. This is due to the fact that, most of the items in this class (XC) are more frequent demanded items with different percentages in each distribution center. The percentage of more frequently demanded items for each distribution center in class (XC) is presented in Table 4.19.

Table 4. 19 Percentage of More Frequent Demanded Items in Class XC

DC	More Frequent Demanded Items(%)
RDC6	33,33%
RDC15	100,00%
RDC19	50,00%

4.4.3. Truck Utilization Analysis:

To show the lack and the weakness of the uncoordinated strategies, the utilization of trucks from upstream locations (warehouses) and the downstream locations is calculated. The maximum utilization of trucks was between the upstream locations and the RDC15. This is due to the fact that RDC15 has the maximum average daily aggregate demand (Figure 3.14). The truck utilization between the upstream locations and RDC15 for each uncoordinated strategy is illustrated in Figure 4.24.

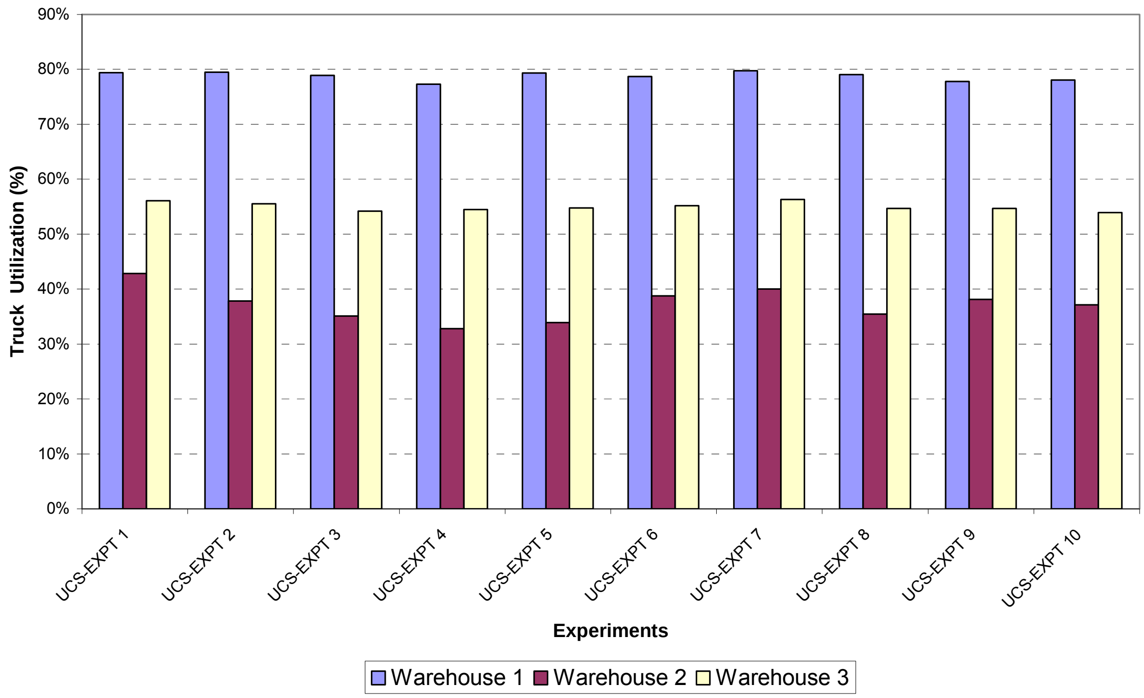

Figure 4. 24 Utilization of Trucks between Upstream Locations and RDC15

From the above figure it is clear that the utilization of trucks is very low, approximately equal 57% on the average. The low value of truck utilization is one of the problems of uncoordinated strategies. This problem produces high transportation costs.

Conclusion:

To estimate, in general, the strategies and make a general conclusion, weighted factors for all measures of performance is given, and then the weighted average factor for all strategies has been calculated, and based on the weighted average factor, the estimating factors of all strategies have been calculated (Table 4.20).

Table 4. 20 Estimation of the Experiments

Experiments	TTC	TIHC	AOLFR	AOFR	Estimating Factor
UCS-Expt 1	4	3	3	3	4
UCS-Expt 2	1	2	5	5	4
UCS-Expt 3	3	1	4	4	3
UCS-Expt 4	5	5	1	1	3
UCS-Expt 5	2	1	3	3	2
UCS-Expt 6	4	4	1	1	2
UCS-Expt 7	3	3	3	2	2
UCS-Expt 8	1	4	2	2	1
UCS-Expt 9	2	2	4	4	3
UCS-Expt 10	1	1	5	5	3

1: Poor
2: Fair
3: Good
4: Very Good
5: Excellent

- Table 4.20 shows that, there is no optimal strategy for all measures of performance in supply chain real networks.
- AOLFR can be correlated with the AOFR.
- The optimal solution of all the indicated problems is to make a new appropriate classification, as will be discussed in the next chapters.
- More attention should be given to designing the reorder points and the maximum inventory level with not only considering the inventory and service levels but also more considering the transportation costs. This can be achieved by giving more attention and consideration of the supply chain coordination. The coordination of inventory and transportation decisions will be presented in the next sections.
- As can be seen, low utilization of trucks is one of the problems commonly encountered when using uncoordinated strategies. Coordination strategies solve this problem, especially when freight rate discounts are offered on the total shipped quantity volume.

5. Coordination Distribution Strategies: Design and Analysis

The main focus of this chapter is the coordination strategies in the supply chain and to show how these strategies can achieve attractive cost savings with improved customer satisfaction.

Savings on unit transportation cost is one of the most important advantages of shipment consolidation or joint replenishment (coordinated replenishment). In the model mentioned in the last chapter, freight rate discounts are offered on the total volume of a replenishment made up of several items. Therefore, it is attractive to use a full truckload concept. Many systems and procedures for continuous or periodic control systems are developed to solve the problem of joint replenishment or coordinated replenishment (shipment consolidation) like can-order systems. Balintfy [Bal64] proposed the use of an (S, c, s) continuous review system for controlling coordinated items. Atkins and Iyogun [AI88] developed a procedure for periodic review control system that out performs can-order policies and which are easier to implement. Miltenburg [Mil87] developed a system which can be used when a discount is offered and if the group order size exceeds some level then it is attractive to achieve a specified group order size. It can be used for either continuous or periodic review systems. For full truck applications, all of the previous methods can be applied but there is no guarantee that the order quantities will generate a full truckload. A reasonable approximation method is developed for full truck application. This method is called a Service Point method with some adaptations for a full truck load [CM88]. In this thesis the developed simulation model can guarantee that and solve the problem of filling the truck exactly. Silver et al. [SPP98] gives additional information and other researches on this topic.

Seven experiments have been designed specially for these purposes.

5.1. Design of Coordination Strategy Experiments:

The coordination strategies are mainly designed to coordinate the transportation decisions and inventory decisions (policies). These strategies are developed by jointing one of the consolidation concepts (Transportation Decisions), which have been described in chapter three with one of the previous uncoordinated strategies (Inventory Decisions). In general, seven coordination strategies are designed. Under these seven strategies, thirty eight experiments are constructed. All of the seven strategies are designed under the same assumptions considered in Chapter 4, and all the experiments are conducted by implementing the simulation model described in Chapter 3.

To conduct the experiments by using the developed simulation model, the user should select the appropriate inventory and replenishment policies for each location in the network. In these experiments, like those in the previous chapter, the downstream locations are selected as “distribution centres” for location type and with “Allowed to keep inventory” as inventory policy. Here the Full-Truck-Load (FTL) strategy is selected as transportation strategy by selecting one of the described consolidation concepts as the replenishment policy.

To construct a coordination strategy, the uncoordinated strategies could be integrated with one of the described consolidation concepts. All of these strategies could be selected through the input data mask parameters (Figure 3.5 and Figure 3.19).

Notation:

- CS--Expt: Coordination Strategy Experiment.
- CS-XXX-Expt: Coordination Strategy combined with one of the consolidation concepts Experiment.

5.1.1. Coordination Strategy Experiments (1) - (CS1-Expt):

In this experiment design, the experiment ABC– Item Strategy (without Safety Stock) is coordinated with all of the six consolidation concepts to generate six coordination strategies. The name of each experiment strategy is described below:

I. Experiment ABC– Item (without Safety Stock) with ABC-Articles (Items) type Coordination Strategy (CS1-ABC-Expt1).
II. Experiment ABC– Item (without Safety Stock) with A-Articles (Items) type Coordination Strategy (CS1-A-Expt2).
III. Experiment ABC– Item (without Safety Stock) with C-Articles (Items) type Coordination Strategy (CS1-C-Expt3).
IV. Experiment ABC– Item (without Safety Stock) with Z-Articles (Items) type Coordination Strategy (CS1-Z-Expt4).
V. Experiment ABC– Item (without Safety Stock) 2-Days Forecasted Demand Coordination Strategy (CS1-2D-Expt5).
VI. Experiment ABC– Item (without Safety Stock) 4-Days Forecasted Demand Coordination Strategy (CS1-4D-Expt6).

As mentioned before, all the experiments are conducted by using the developed simulation model.

5.1.2. Coordination Strategy Experiments (2) - (CS2-Expt):

The experiment ABC–Item Strategy (with Safety Stock) is coordinated with all of the six consolidation concepts to generate six coordination strategies as in the above experiment design. The experiments are:

I. Experiment ABC–Item (with Safety Stock) with ABC-Articles type Coordination Strategy (CS2-ABC-Expt1).
II. Experiment ABC–Item (with Safety Stock) with A-Articles type Coordination Strategy (CS2-A-Expt2).

III. Experiment ABC– Item (with Safety Stock) with C-Articles type Coordination Strategy (CS2-C-Expt3).
IV. Experiment ABC–Item (with Safety Stock) with Z-Articles type Coordination Strategy (CS2-Z-Expt4).
V. Experiment ABC–Item (with Safety Stock) with 2-Days Forecasted Demand Coordination Strategy (CS2-2D-Expt5).
VI. Experiment ABC–Item (with Safety Stock) with 4-Days Forecasted Demand Coordination Strategy (CS2-4D-Expt6).

The developed simulation model is implemented to conduct all the experiments

5.1.3. Coordination Strategy Experiments (3) - (CS3-Expt):

As is the case in the last two experiment designs, the experiment ABC-Item Strategy (minimization of transportation) is integrated with the six consolidation concepts to generate six strategy experiments. The followings are the designed experiments:

I. Experiment ABC–Item (minimization of transportation) with ABC-Articles type Coordination Strategy (CS3-ABC-Expt1).
II. Experiment ABC–Item (minimization of transportation) with A-Articles type Coordination Strategy (CS3-A-Expt2).
III. Experiment ABC–Item (minimization of transportation) with C-Articles type Coordination Strategy (CS3-C-Expt3).
IV. Experiment ABC–Item (minimization of transportation) with Z-Articles type Coordination Strategy (CS3-Z-Expt4).
V. Experiment ABC–Item (minimization of transportation) with 2-Days Forecasted Demand Coordination Strategy (CS3-2D-Expt5).
VI. Experiment ABC–Item (minimization of transportation) with 4-Days Forecasted Demand Coordination Strategy (CS3-4D-Expt6).

5.1.4. Coordination Strategy Experiments (4) - (CS4-Expt):

To study the effect of consolidation concepts on the allocation strategy only four consolidation concepts are selected to coordinate with the base strategy (Experiment C-Item Allocation Coordination Strategy). Four new coordination strategies are constructed. These are:

I. Experiment C-Item Allocation with ABC-Articles type Coordination Strategy (CS4-ABC-Expt1).
II. Experiment C-Item Allocation with C-Articles type Coordination Strategy (CS4-C-Expt2).
III. Experiment C-Item Allocation with 2-Days Forecasted Demand Coordination Strategy (CS4-2D-Expt3).
IV. Experiment C-Item Allocation with 4-Days Forecasted Demand Coordination Strategy (CS4-4D-Expt4).

5.1.5. Coordination Strategy Experiments (5) - (CS5-Expt):

As is the case in the previous experiment design, four consolidation concepts are selected and coordinated with the uncoordinated strategy (Experiment Z-Item Allocation Strategy) to construct four coordination strategies. These strategies are:

I. Experiment Z-Item Allocation with ABC-Articles type Coordination Strategy (CS5-ABC-Expt1).
II. Experiment Z-Item Allocation with Z-Articles type Coordination Strategy (CS5-Z-Expt2).
III. Experiment Z-Item Allocation with 2-Days Forecasted Demand Coordination Strategy (CS5-2D-Expt3).
IV. Experiment Z-Item Allocation with 4-Days Forecasted Demand Coordination Strategy (CS5-4D-Expt4).

5.1.6. Coordination Strategy Experiments (6) - (CS6-Expt):

In this experiment design, all of the six consolidation concepts are selected and integrated with the base strategy (Experiment CSL (80%) ABC Item Strategy) to generate new six coordination strategies. The new coordination strategies will be compared with the uncoordinated strategy (base). The descriptions of all the experiments are:

I. Experiment CSL (80%) ABC Item with ABC-Articles type Coordination Strategy (CS6-ABC-Expt1).
II. Experiment CSL (80%) ABC Item with A-Articles type Coordination Strategy (CS6-A-Expt2).
III. Experiment CSL (80%) ABC Item with C-Articles type Coordination Strategy (CS6-C-Expt3).
IV. Experiment CSL (80%) ABC Item with Z-Articles type Coordination Strategy (CS6-Z-Expt4).
V. Experiment CSL (80%) ABC Item with 2-Days Forecasted Demand Coordination Strategy (CS6-2D-Expt5).
VI. Experiment CSL (80%) ABC Item with 4-Days Forecasted Demand Coordination Strategy (CS6-4D-Expt6).

5.1.7. Coordination Strategy Experiments (7) - (CS7-Expt):

This experiment design is the same as the above experiment design but the difference is only in the selection of the uncoordinated strategy. The uncoordinated strategy is the experiment CSL (90%) ABC Item Strategy (base). The six generated strategy experiments are:

I. Experiment CSL (90%) ABC Item with ABC-Articles type Coordination Strategy (CS7-ABC-Expt1).
II. Experiment CSL (90%) ABC Item with A-Articles type Coordination Strategy (CS7-A-Expt2).

III. Experiment CSL (90%) ABC Item with C-Articles type Coordination Strategy (CS7-C-Expt3).

IV. Experiment CSL (90%) ABC Item with Z-Articles type Coordination Strategy (CS7-Z-Expt4).

V. Experiment CSL (90%) ABC Item with 2-Days Forecasted Demand Coordination Strategy (CS7-2D-Expt5).

VI. Experiment CSL (90%) ABC Item with 4-Days Forecasted Demand Coordination Strategy (CS7-4D-Expt6).

The general structure of the design of all the seven coordination strategies is summarized in Table 5.1.

Table 5. 1 General Structure of Coordination Strategies Design

Expt-Name	Uncoordinated Strategy Expt.							Consolidation Concept					
	UCS- Expt 1	UCS- Expt 2	UCS- Expt 3	UCS- Expt 4	UCS- Expt 6	UCS- Expt 9	UCS- Expt 10	ABC	A	C	Z	2D	4D
CS1-Expt	✓	-	-	-	-	-	-	✓	✓	✓	✓	✓	✓
CS2-Expt	-	✓	-	-	-	-	-	✓	✓	✓	✓	✓	✓
CS3-Expt	-	-	✓	-	-	-	-	✓	✓	✓	✓	✓	✓
CS4-Expt	-	-	-	✓		-	-	✓	-	✓	-	✓	✓
CS5-Expt	-	-	-	-	✓	-	-	✓	-	-	✓	✓	✓
CS6-Expt	-	-	-	-	-	✓	-	✓	✓	✓	✓	✓	✓
CS7-Expt	-	-	-	-	-	-	✓	✓	✓	✓	✓	✓	✓

✓	Integrated
-	Not Integrated

5.2. Experimental Simulation Results

Many results have been collected and analyzed after running the developed simulation model for one year. The same measures of performance as used in the last chapter are also calculated here. For comparing the results, the uncoordinated strategies have been taken as the base experiments to be compared with the new coordination strategies. The average order fill rate (AOFR) is selected as the first and important measure of performance. The following section presents the results and analysis of these results.

5.2.1. Results of Coordination Strategy Experiments (1)

The simulation results of these experiments are summarized and the measures of performance are calculated and ranked in ascending order based on the average order fill rate (AOFR) as shown in Table 5.2 and Figure 5.1.

Table 5. 2 Measures of Performance of Each Coordination Strategy for Coordination Strategy Experiments (1)

Experiments	TTC	TIHC	TLC	AOLFR	AOFR
CS1-4D-Expt6	$8.039.851,27	$268.930,82	$8.308.782,09	98,87%	89,27%
CS1-ABC-Expt1	$8.687.533,81	$2.341.572,03	$11.029.105,84	98,74%	84,82%
CS1-C-Expt3	$11.510.425,29	$5.717.147,31	$17.227.572,60	97,31%	68,04%
CS1-A-Expt2	$10.639.802,17	$4.429.948,84	$15.069.751,01	97,55%	67,50%
CS1-2D-Expt5	$8.105.428,01	$274.111,20	$8.379.539,21	96,76%	66,13%
CS1-Z-Expt4	$11.455.651,84	$5.574.419,35	$17.030.071,19	97,01%	65,92%
UCS-Expt 1*	$8.114.944,57	$276.000,10	$8.390.944,67	96,44%	61,06%

* Base Experiment

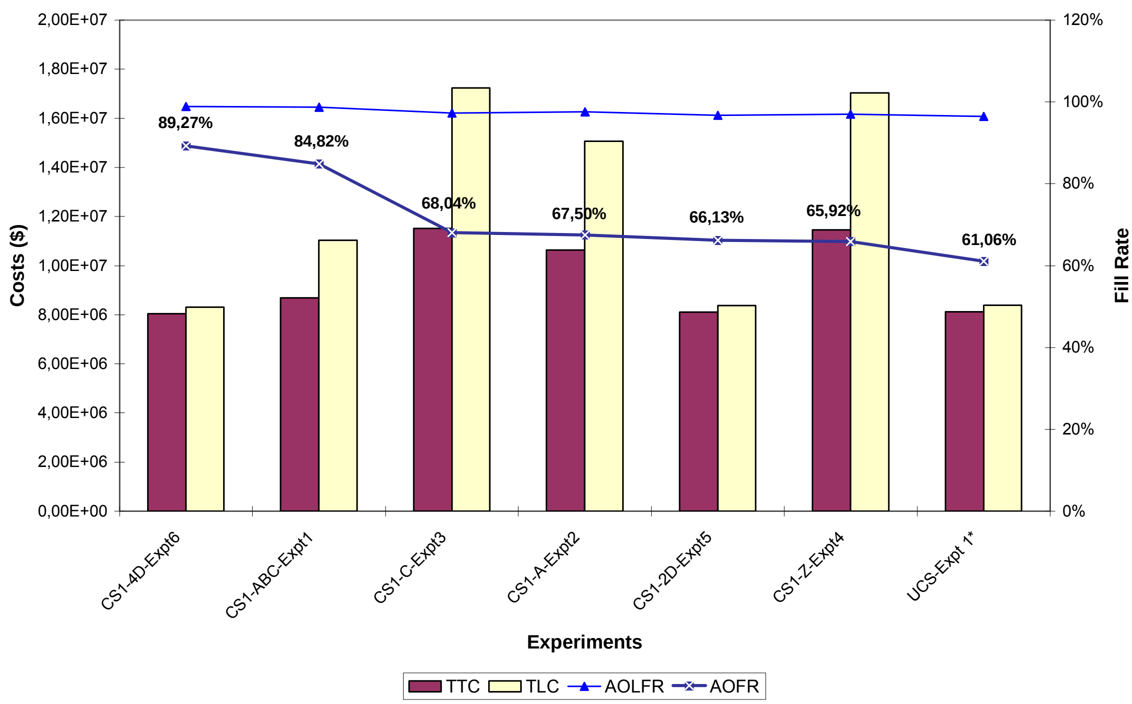

Figure 5. 1 Measures of Performance of Each Strategy for Coordination Strategy Experiments (1)

5.2.2. Results of Coordination Strategy Experiments (2)

The measures of performance of each strategy based on the ascending order of average order fill rate (AOFR) are presented in Table 5.3 and Figure 5.2.

Table 5. 3 Measures of Performance of Each Coordination Strategy for Coordination Strategy Experiments (2)

Experiments	TTC	TIHC	TLC	AOLFR	AOFR
CS2-4D-Expt6	$8.132.842,11	$318.010,96	$8.450.853,07	99,69%	97,14%
CS2-ABC-Expt1	$8.945.934,57	$2.773.991,36	$11.719.925,93	99,53%	94,61%
CS2-C-Expt3	$11.972.692,77	$6.399.221,14	$18.371.913,91	99,06%	88,12%
CS2-Z-Expt4	$11.766.785,39	$6.048.990,65	$17.815.776,04	99,00%	88,05%
CS2-A-Expt2	$11.003.937,31	$4.933.961,77	$15.937.899,08	99,09%	86,47%
CS2-2D-Expt5	$8.146.000,17	$319.955,78	$8.465.955,95	98,82%	86,09%
UCS-Expt 2*	$8.149.488,60	$321.158,15	$8.470.646,75	98,68%	83,65%

* Base Experiment

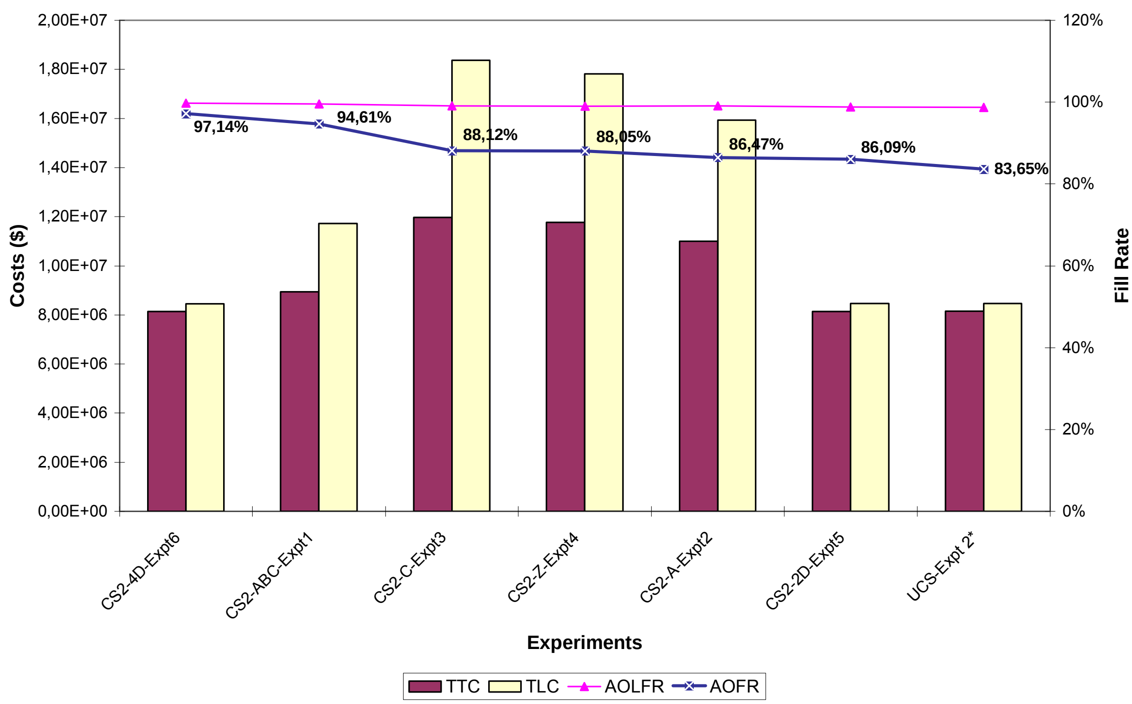

Figure 5. 2 Measures of Performance of Each Strategy for Coordination Strategy Experiments (2)

5.2.3. Results of Coordination Strategy Experiments (3)

As in previous experiments, the measures of performance of each strategy are given in Table 5.4 and Figure 5.3.

Table 5. 4 Measures of Performance of Each Coordination Strategy for Coordination Strategy Experiments (3)

Experiments	TTC	TIHC	TLC	AOLFR	AOFR
CS3-4D-Expt6	$8.103.591,95	$340.000,96	$8.443.592,91	99,50%	94,74%
CS3-A-Expt2	$11.178.345,65	$5.185.475,66	$16.363.821,31	99,30%	89,54%
CS3-ABC-Expt1	$8.788.238,45	$2.578.447,63	$11.366.686,08	99,12%	89,16%
CS3-Z-Expt4	$11.767.926,44	$6.067.614,39	$17.835.540,83	98,44%	80,67%
CS3-2D-Expt5	$8.121.995,18	$343.017,62	$8.465.012,80	98,30%	79,77%
CS3-C-Expt3	$11.786.583,89	$6.155.959,19	$17.942.543,08	98,28%	78,40%
UCS-Expt 3*	$8.125.338,06	$344.206,49	$8.469.544,55	98,17%	77,19%

* Base Experiment

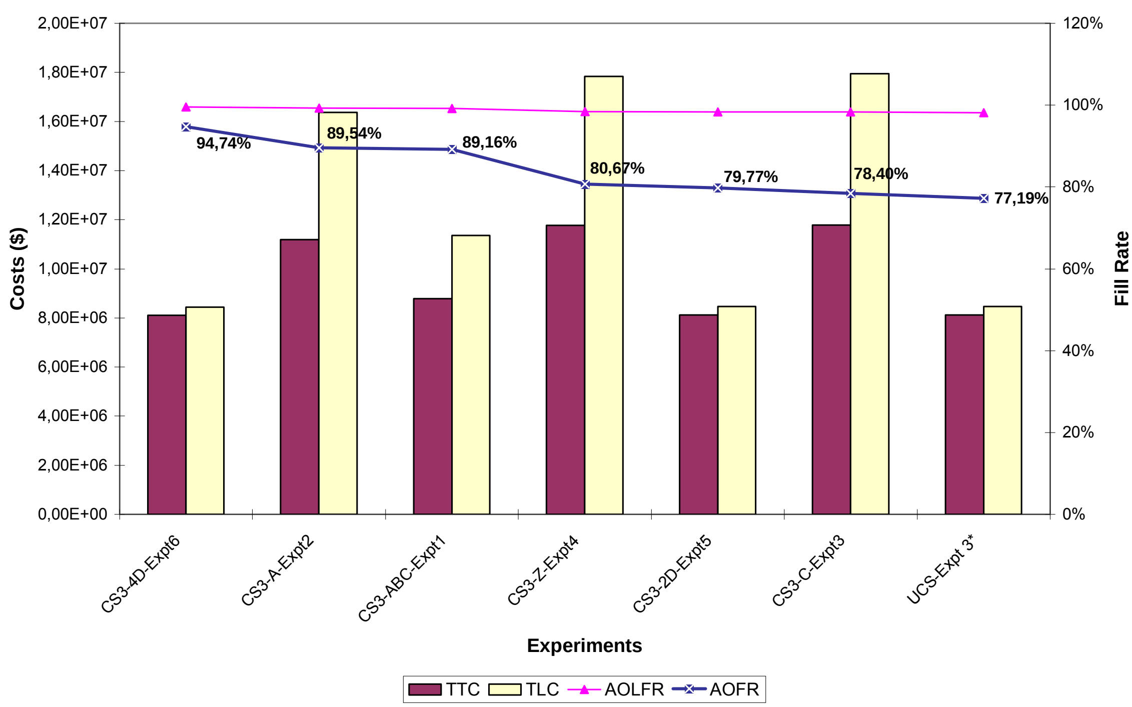

Figure 5. 3 Measures of Performance of Each Strategy for Coordination Strategy Experiments (3)

5.2.4. Results of Coordination Strategy Experiments (4)

The results of these experiments are shown in Table 5.5 and Figure 5.4.

Table 5. 5 Measures of Performance of Each Coordination Strategy for Coordination Strategy Experiments (4)

Experiments	TTC	TIHC	TLC	AOLFR	AOFR
CS4-4D-Expt4	$7.928.724,62	$180.621,99	$8.109.346,61	97,84%	80,82%
CS4-ABC-Expt1	$8.727.735,23	$2.348.033,66	$11.075.768,89	97,70%	75,51%
CS4-C-Expt2	$11.519.417,05	$5.668.792,86	$17.188.209,91	96,69%	62,99%
CS4-2D-Expt3	$8.007.420,01	$189.960,61	$8.197.380,62	92,50%	39,15%
UCS-Expt 4*	$8.109.584,95	$205.694,79	$8.315.279,74	86,49%	10,10%

* Base Experiment

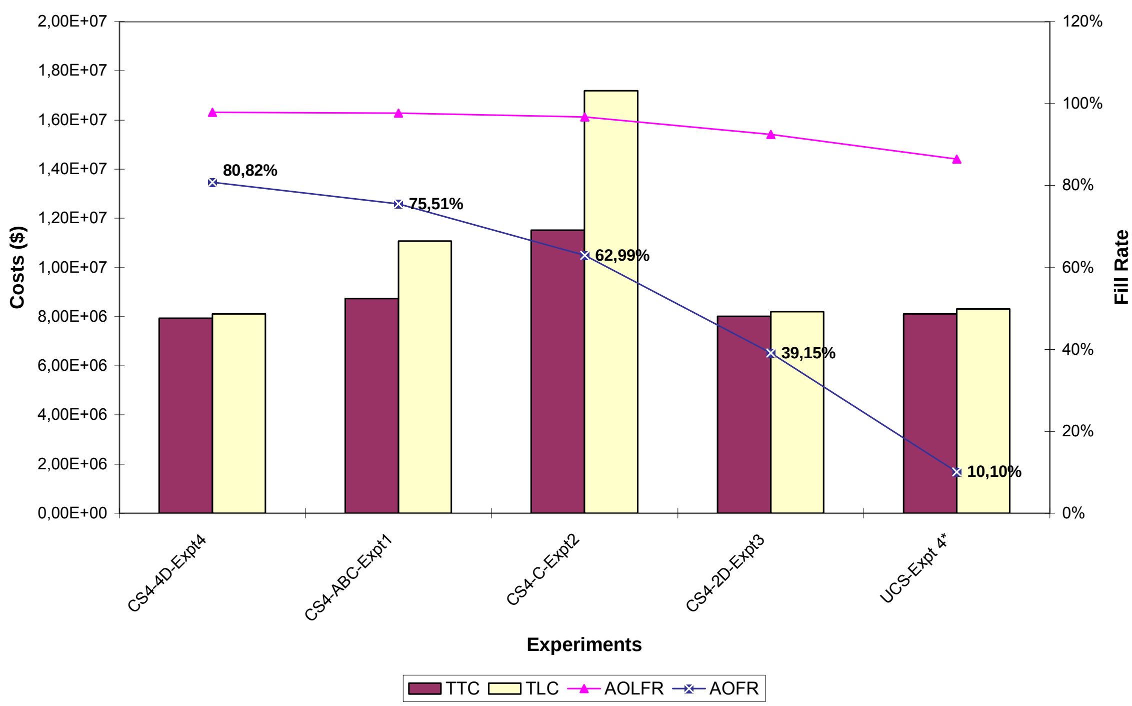

Figure 5. 4 Measures of Performance of Each Strategy for Coordination Strategy Experiments (4)

5.2.5. Results of Coordination Strategy Experiments (5)

The results are summarized in Table 5.6 and Figure 5.5.

Table 5. 6 Measures of Performance of Each Coordination Strategy for Coordination Strategy Experiments (5)

Experiments	TTC	TIHC	TLC	AOLFR	AOFR
CS5-4D-Expt4	$7.965.066,71	$208.856,65	$8.173.923,36	98,11%	82,84%
CS5-ABC-Expt1	$8.855.015,91	$2.560.146,74	$11.415.162,65	96,70%	58,05%
CS5-Z-Expt2	$11.463.174,72	$5.545.677,91	$17.008.852,63	96,21%	56,97%
CS5-2D-Expt3	$8.043.576,01	$217.498,18	$8.261.074,19	93,17%	42,88%
UCS-Expt 6*	$8.116.662,30	$233.927,36	$8.350.589,66	88,91%	12,98%

* Base Experiment

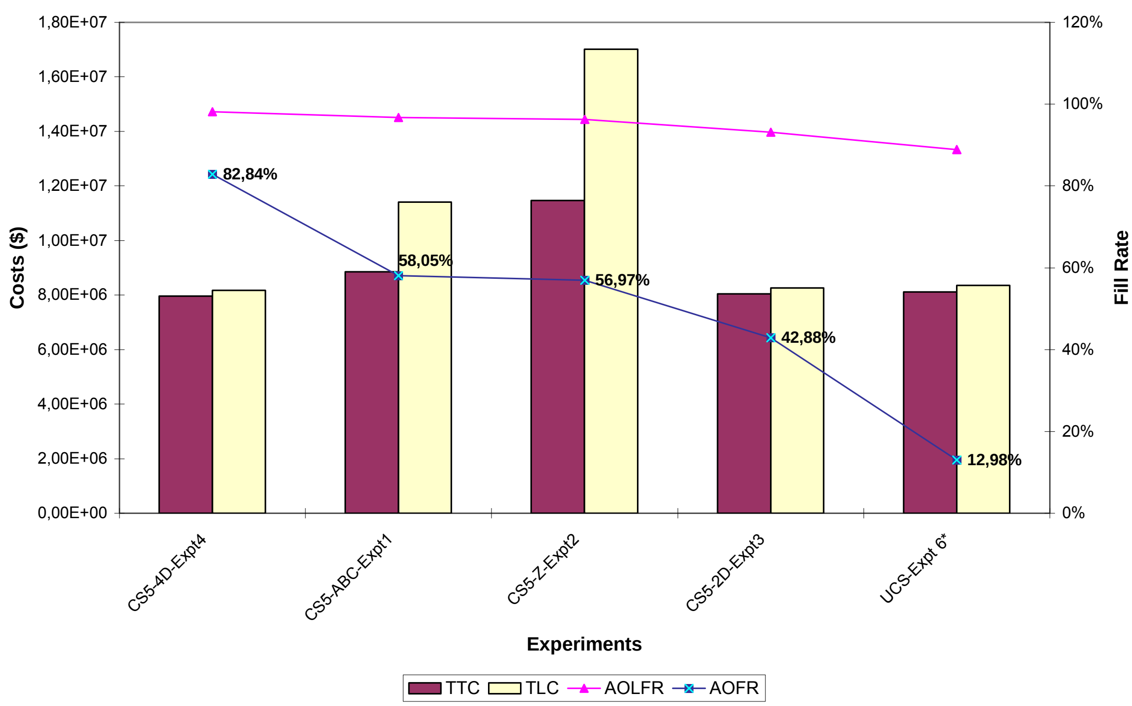

Figure 5. 5 Measures of Performance of Each Strategy for Coordination Strategy Experiments (5)

5.2.6. Results of Coordination Strategy Experiments (6)

The measures of performance are estimated and presented in Table 5.7 and Figure 5.6.

Table 5. 7 Measures of Performance of Each Coordination Strategy for Coordination Strategy Experiments (6)

Experiments	TTC	TIHC	TLC	AOLFR	AOFR
CS6-4D-Expt6	$8.113.603,89	$312.881,40	$8.426.485,29	99,52%	95,39%
CS6-ABC-Expt1	$8.863.932,25	$2.667.211,44	$11.531.143,69	99,35%	92,74%
CS6-C-Expt3	$11.800.758,53	$6.157.632,97	$17.958.391,50	98,65%	83,03%
CS6-A-Expt2	$10.894.912,99	$4.789.759,82	$15.684.672,81	98,82%	82,67%
CS6-Z-Expt4	$11.642.805,24	$5.865.654,06	$17.508.459,30	98,49%	81,80%
CS6-2D-Expt5	$8.135.225,14	$315.905,35	$8.451.130,49	98,37%	81,02%
UCS-Expt 9*	$8.139.772,59	$317.015,50	$8.456.788,09	98,23%	78,45%

* Base Experiment

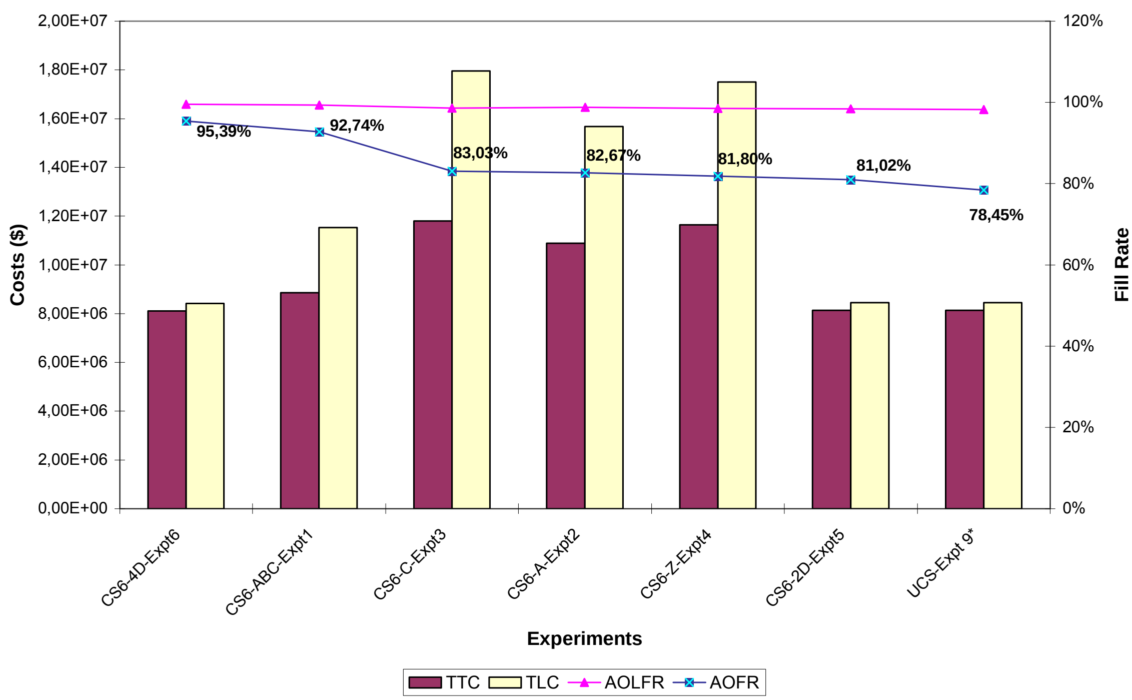

Figure 5. 6 Measures of Performance of Each Strategy for Coordination Strategy Experiments (6)

5.2.7. Results of Coordination Strategy Experiments (7)

The measures of performance are calculated and presented in Table 5.8 and Figure 5.7.

Table 5. 8 Measures of Performance of Each Coordination Strategy for Coordination Strategy Experiments (7)

Experiments	TTC	TIHC	TLC	AOLFR	AOFR
CS7-4D-Expt6	$8.128.735,31	$338.034,68	$8.466.769,99	99,69%	96,78%
CS7-ABC-Expt1	$9.011.188,75	$2.876.555,01	$11.887.743,76	99,52%	94,60%
CS7-C-Expt3	$11.959.254,33	$6.387.193,00	$18.346.447,33	99,02%	87,52%
CS7-A-Expt2	$10.996.591,27	$4.974.371,04	$15.970.962,31	99,17%	87,38%
CS7-Z-Expt4	$11.739.426,40	$6.030.849,88	$17.770.276,28	98,92%	87,06%
CS7-2D-Expt5	$8.148.532,70	$340.068,95	$8.488.601,65	98,83%	86,12%
UCS-Expt 10*	$8.150.344,06	$340.914,26	$8.491.258,32	98,72%	84,08%

* Base Experiment

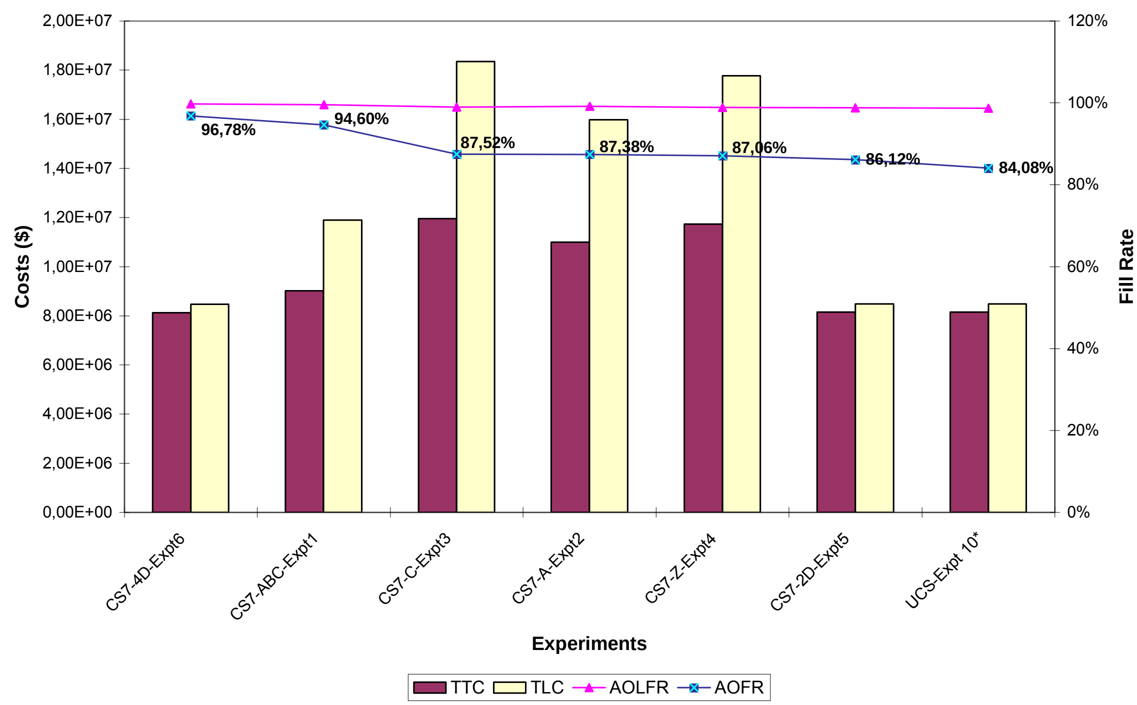

Figure 5. 7 Measures of Performance of Each Strategy for Coordination Strategy Experiments (7)

5.3. Analysis of Simulation Results

In this section all the analysis and interpretation of the results (measures of performance) are presented.

5.3.1. Logistics Costs and Fill Rate Analysis

From the investigations of the previous tables and figures, some findings are notable:

- Coordination strategies perform better than the uncoordinated strategies.
- In all seven experiments the 4-Days Forecasted Demand and the ABC-Articles type consolidation concepts are the optimal strategies for improving the uncoordinated strategies and system performances, respectively, especially in terms of OFR.

The above findings can be proven by selecting CS6-Expt coordination experiment design as an example. The improvement on the average of the order fill rate using each consolidation concept is calculated as a percentage of the base experiment (uncoordinated strategy) using equation (5.1) and shown in Figure 5.8.

Improvement of Average Order Fill Rate by each Coordination Strategy (%) =

$$\frac{AOFR\ of\ \ coordination\ strategy - AOFR\ of\ \ uncoordinated\ \ strategy}{AOFR\ of\ \ uncoordinated\ \ strategy} x100\% \qquad (5.1)$$

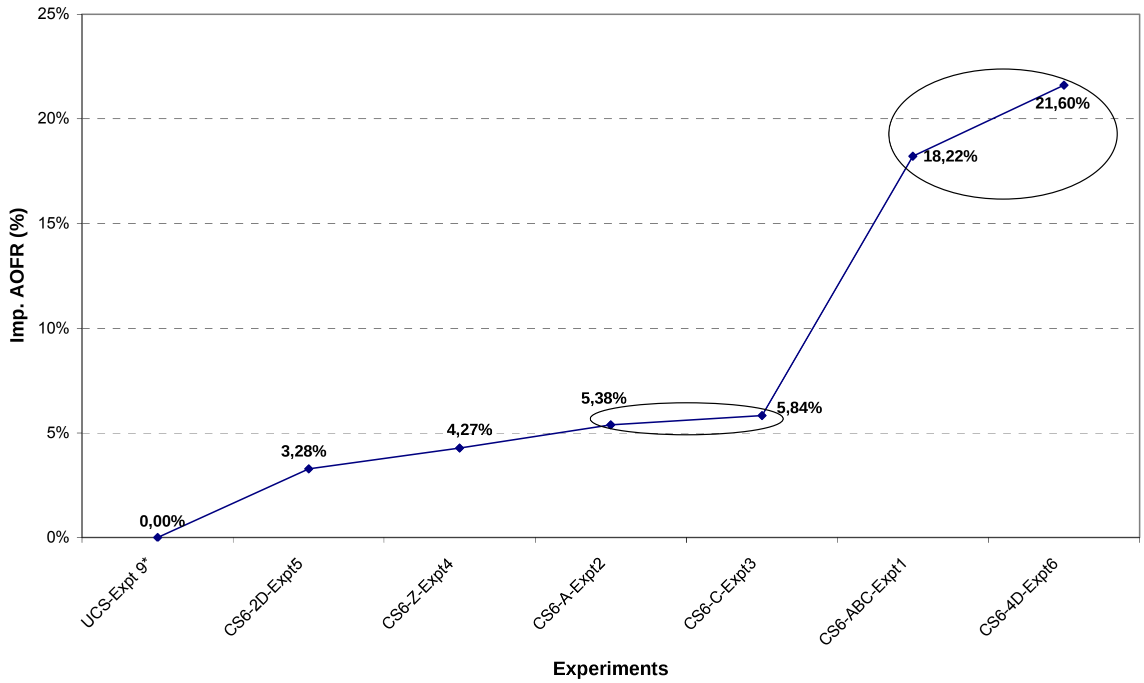

Figure 5. 8 Improvement of Order Fill Rate by Using Selected Consolidation Concepts in Coordination Strategy Experiments (6)

Additionally, the percentage of increase in the total logistics costs resulting from applying of the coordination strategies as compared with the uncoordinated strategy (base) is calculated using equation (5.2) and shown in Figure 5.9.

Increase in Total Logistics Costs by Each Coordination Strategy (%) =

$$\frac{TLC\ of\ coordination\ strategy - TLC\ of\ uncoordinated\ strategy}{TLC\ of\ uncoordinated\ strategy} x100\% \qquad (5.2)$$

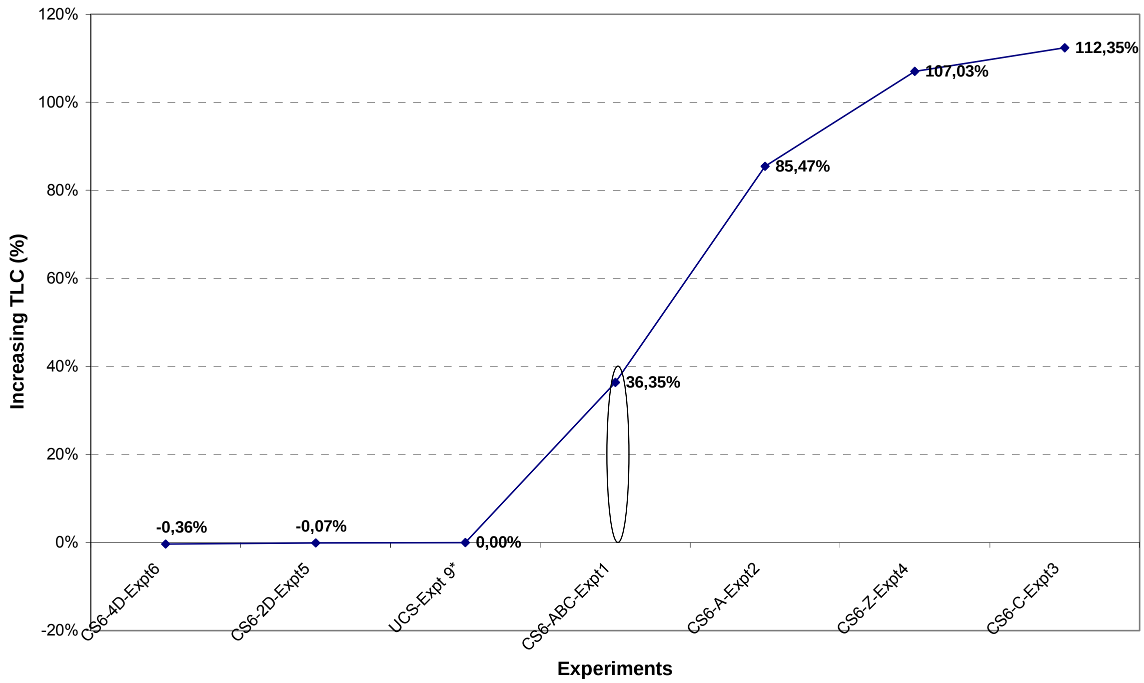

Figure 5. 9 Increase in Total Logistics Costs by Using Selected Consolidation Concepts in Coordination Strategy Experiments (6)

The optimality of the 4-Days Forecasted Demand consolidation concept can be justified by the fact that, this concept produces less inventory and transportation due to the strength of the logic of the concept as explained in chapter 3. By this concept, the truck will be highly utilized and a greater saving on transportation cost is achievable. By this concept the average ending inventory is also reduced due to the fact that the stock level of most items will be increased more than the reorder point (s). This reduces the number of replenishments which in turn reduces the total replenishment quantities, especially when the control parameters (s, S) of uncoordinated strategies produce large replenishment quantities. Detailed explanation has been made in the next chapter.

- The value of improving the service level (order fill rate) by applying coordination strategies is more attractive when there is inappropriate uncoordinated strategy. To show this fact, five general coordination design strategies with the two optimal consolidation concepts (4-Days Forecasted Demand and the ABC-Articles type) for each coordination design strategy are selected. For more comparisons, the percentage of improving average order fill rate and the percentage of increasing or decreasing the total logistics costs by the two consolidation concepts for each coordination strategy are calculated using equations (5.1), (5.2) and (5.3) and shown in Figures 5.10, 5.11, 5.12, and 5.13.

Decrease in Total Logistics Costs by Each Coordination Strategy (%) =

$$\frac{TLC\ of\ uncoordinated\ strategy - TLC\ of\ coordination\ strategy}{TLC\ of\ uncoordinated\ strategy} x100\% \qquad (5.3)$$

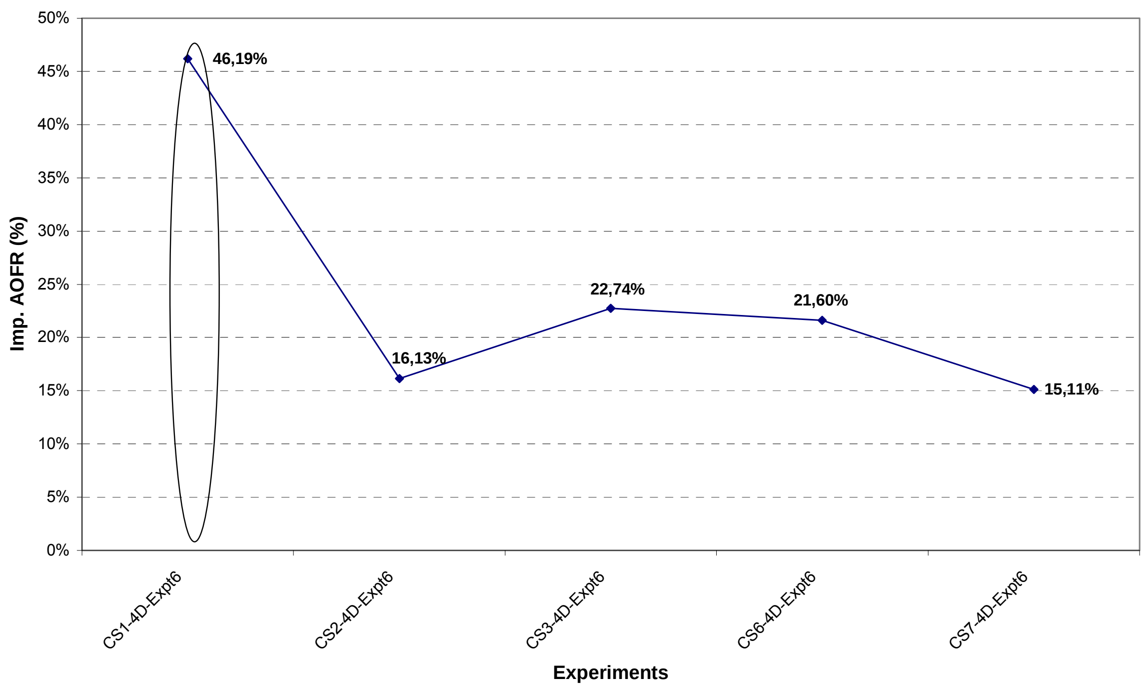

Figure 5. 10 Improvement in Order Fill Rate by 4-Days Forecasted Demand Concept for Each Coordination Strategy

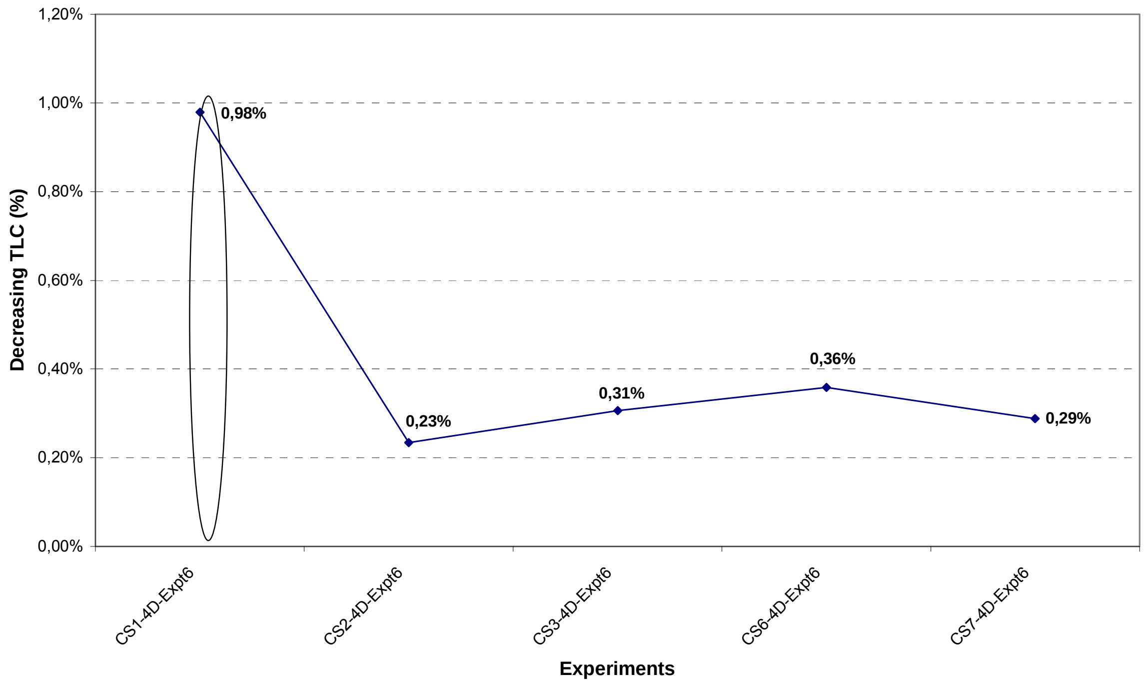

Figure 5. 11 Decrease in Total Logistics Costs by 4-Days Forecasted Demand Concept for Each Coordination Strategy

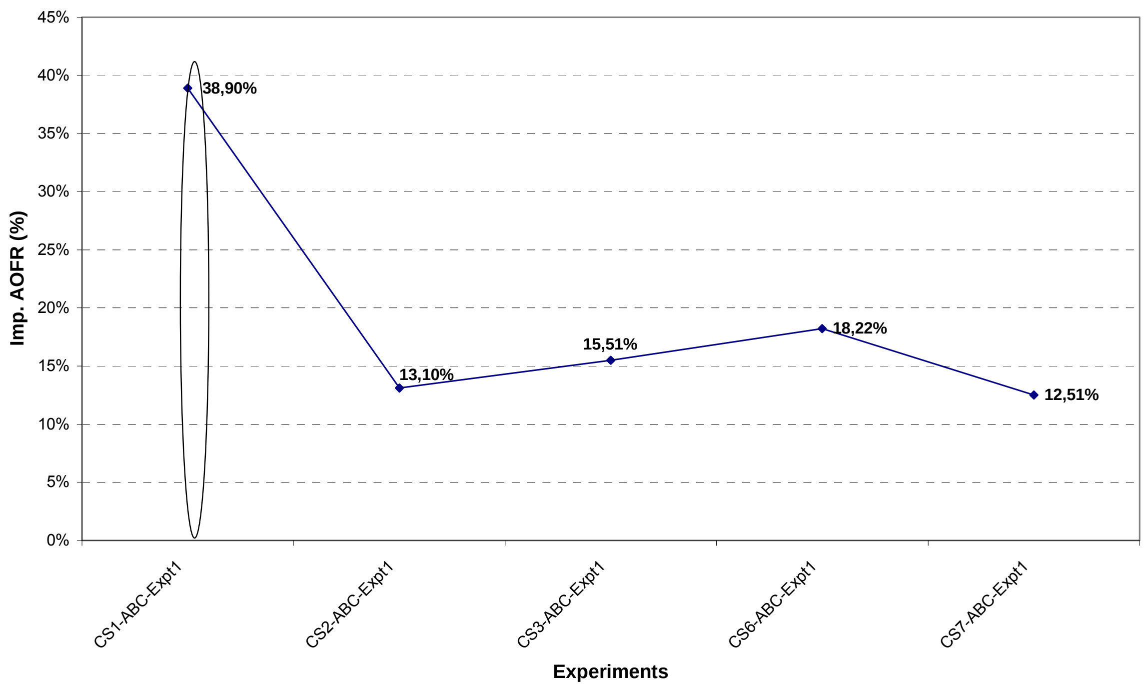

Figure 5. 12 Improvement in Order Fill Rate by ABC-Articles type Concept for Each Coordination Strategy

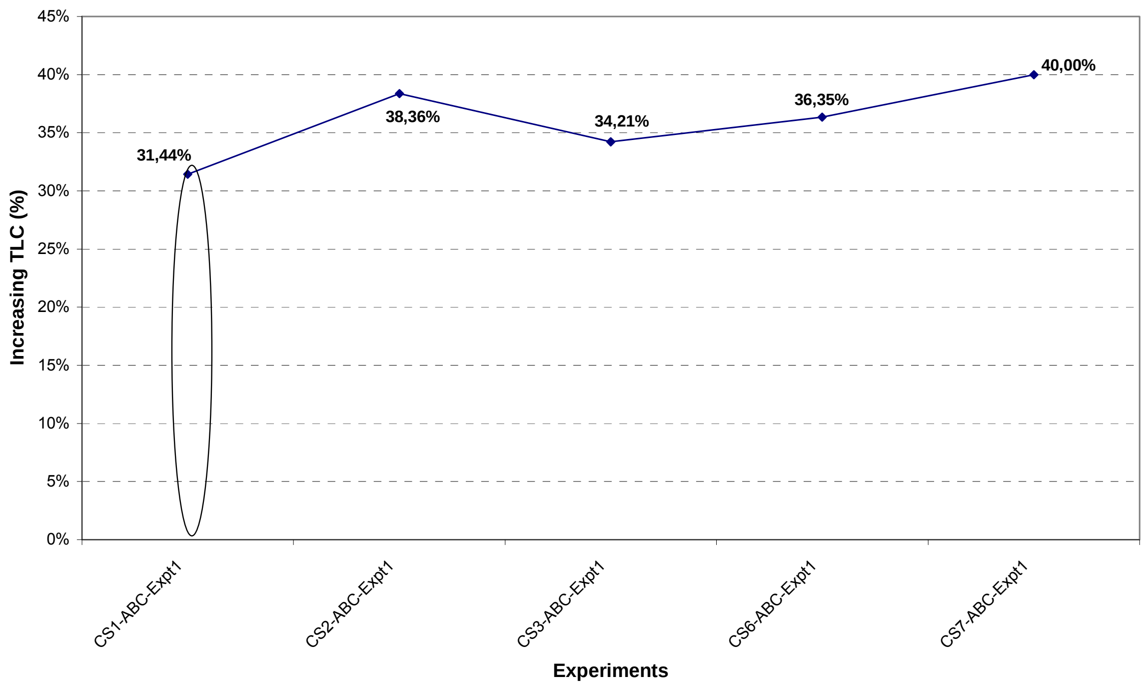

Figure 5. 13 Increase in Total Logistics Costs by ABC-Articles type Concept for Each Coordination Strategy

- The optimal consolidation concept (4-Days Forecasted Demand) improves the service levels (AOFR) on the average by 24% without increasing the total logistic costs (Figure 5.10 and Figure 5.11).

- The second optimal coordination strategy (ABC-Articles type) improves the service levels (Order Fill Rate) on the average by 20% and increases the total logistic costs on the average by 36% (Figure 5.12 and Figure 5.13).
- The figures (5.10and 5.12) illustrate that the service level (Order Fill Rate) of inappropriate distribution strategies is highly improved by using an appropriate coordination strategy.
- In most of the experiments the A-Articles type consolidation concept strategy performs better than the C-Articles type consolidation concept

for improving system performances in terms of total logistics costs. In some cases, however, C-type articles consolidation concept gives a slight improvement in the Average Order Fill Rate. To show this, the coordination strategy experiments (1) - (CS1-Expt) are selected and the results are show in Figure 5.14 and Figure 5.15. It can be explained by the fact that the C-items represent the highest percentage of the total items, as shown in Table 4.1 and Figure 4.5. This percentage affects the availability of items and, therefore, the C-type articles (Items) consolidation concept increases the availability of C-items at the downstream locations which finally increases the efficiency of delivering the completed orders (AOFR). The significant differences in measures of performance by using these two consolidation concepts (A and C) enhance the importance of using an appropriate items classification approach, as will be seen in the next chapter.

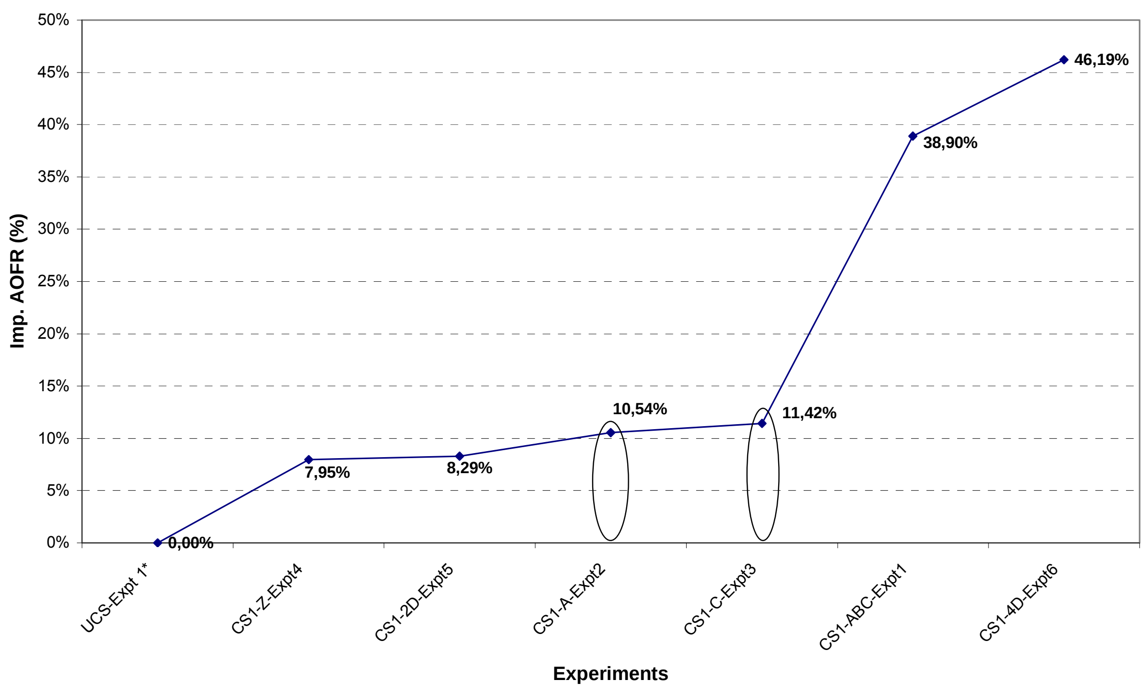

Figure 5. 14 Improvement in Order Fill Rate by Using Selected Consolidation Concepts in Coordination Strategy Experiments (1)

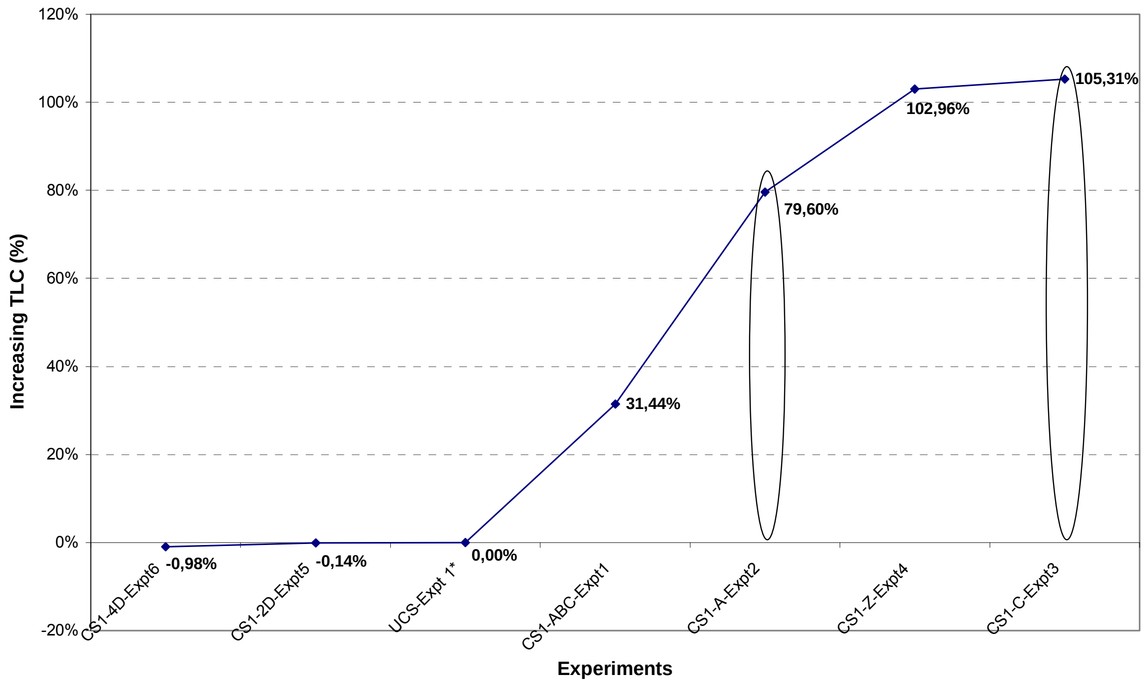

Figure 5. 15 Increase in the Total Logistics Costs by Using Selected Consolidation Concepts in Coordination Strategy Experiments (1)

- The interaction between the design of reorder points based on item type and the item classification consolidation concept is remarkable. For example, from the results, it was clear that in most of the coordination experiments the ABC-Articles type consolidation concept performs better than the other item classification consolidation concepts (A, C and Z) especially when the design of reorder points of all the items types is the same (Tables 5.2, 5.3, 5.7 and 5.8). In the coordination strategy experiments (3) the A-Articles (Items) type consolidation concept performs better than the ABC-Articles type consolidation concept in terms of AOFR (Table 5.4). This can be justified by the fact that, the design of the reorder point of A item type in uncoordinated strategy (UCS-Expt 3) is different from the other items types. The value of the s parameter for A-type items is the smallest (Table 4.14). Therefore the A-Articles (Items) type consolidation concept can increase the availability of A items which increases the efficiency of delivering the completed orders (AOFR). This means that the reorder point of A item type is inappropriate and should be redesigned. Also, for further explanation of this interaction, consider as an example the coordination strategy experiments (2) where the uncoordinated strategy (UCS- 2) gives more values of the s parameter for A-type items (More safety stock), the A-Articles (Items) type consolidation concept performs very badly compared to other consolidation concepts (Table 5.3). This means that the reorder point (s) of A items type was designed perfectly by uncoordinated strategy and there is no need to increase the availability of this item type. Furthermore, the ABC-Articles type consolidation concept in the coordination strategy experiments (2) performs better than in the other coordination strategy experiments in terms of AOFR. This is interpreted by the good design of the reorder points (s) of all items types (A, B and C) by the uncoordinated strategy (UCS- 2).

- In most cases the TLC and AOLFR is correlated with AOFR.

Here, the problem of the large increase in the percentage of total logistics cost is recognized, especially when the item (Article) classification consolidation concept is used in coordination strategies. This is mainly due to the huge size of shipment quantity (replenishment quantity) which was produced from the logic of these consolidation concepts. The increase in the shipment size causes an increase both in transportation and inventory costs. The problem is mainly due to the complex structure of transportation cost rates in the considered real life problem (Table 3.20). The potential saving in transportation cost by using a full truck load under this cost structure is not really attractive. The relationship between the pallet number and the discount in cost tariff is not linear, as shown in Figures 5.16, 5.17, and 5.18. To explain that, the data from Table 3.20 is illustrated in Figure 5.19 and is used to calculate the correlation coefficient between the number of pallets and the transportation cost reduction for the selected three regional distribution centers. The correlation coefficients are shown in Table 5.9. The relationship between the number of pallets and the truck utilization is also presented in Figure 5.20. In general, a uniform increase in truck utilization for *n* total number of pallets may be expressed as *U, 2U, ……………., (n-1)U .*

Table 5. 9 Correlation Coefficient between Number of Pallets and Reduction in Transportation Cost

DC	Correlation Coefficient
RDC9	0,741851974
RDC13	0,773806665
RDC19	0,857383295

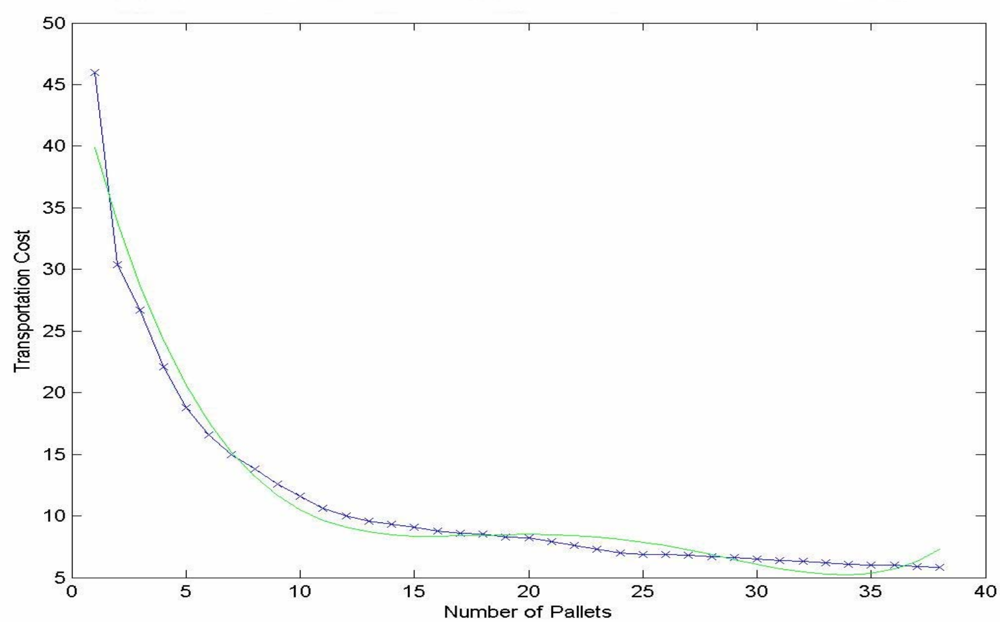

Figure 5. 16 Real Curve and Fitted Curve of Transportation Cost ($) Function in RDC9

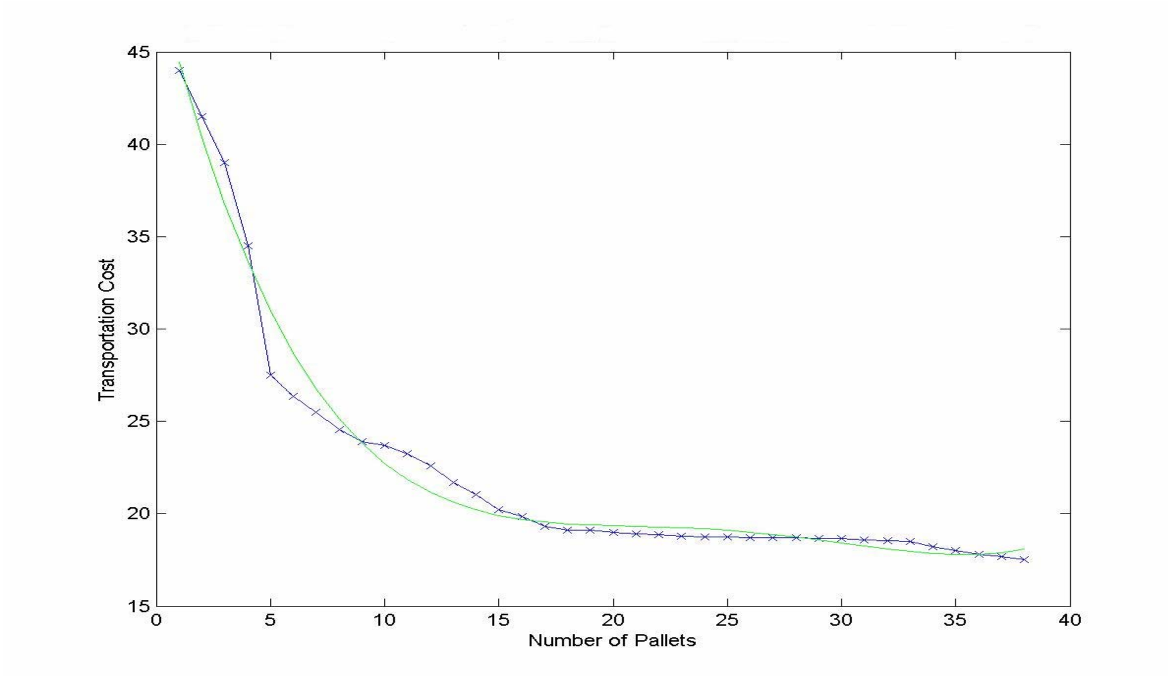

Figure 5. 17 Real Curve and Fitted Curve of Transportation Cost ($) Function in RDC13

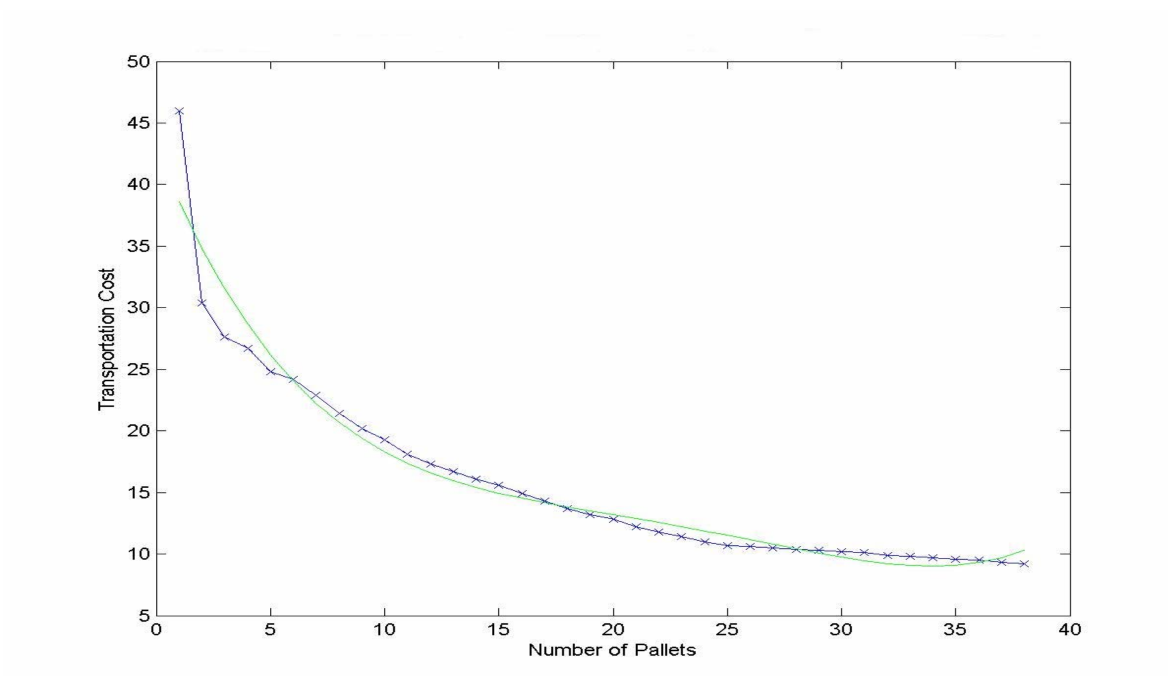

Figure 5. 18 Real Curve and Fitted Curve of Transportation Cost ($) Function in RDC19

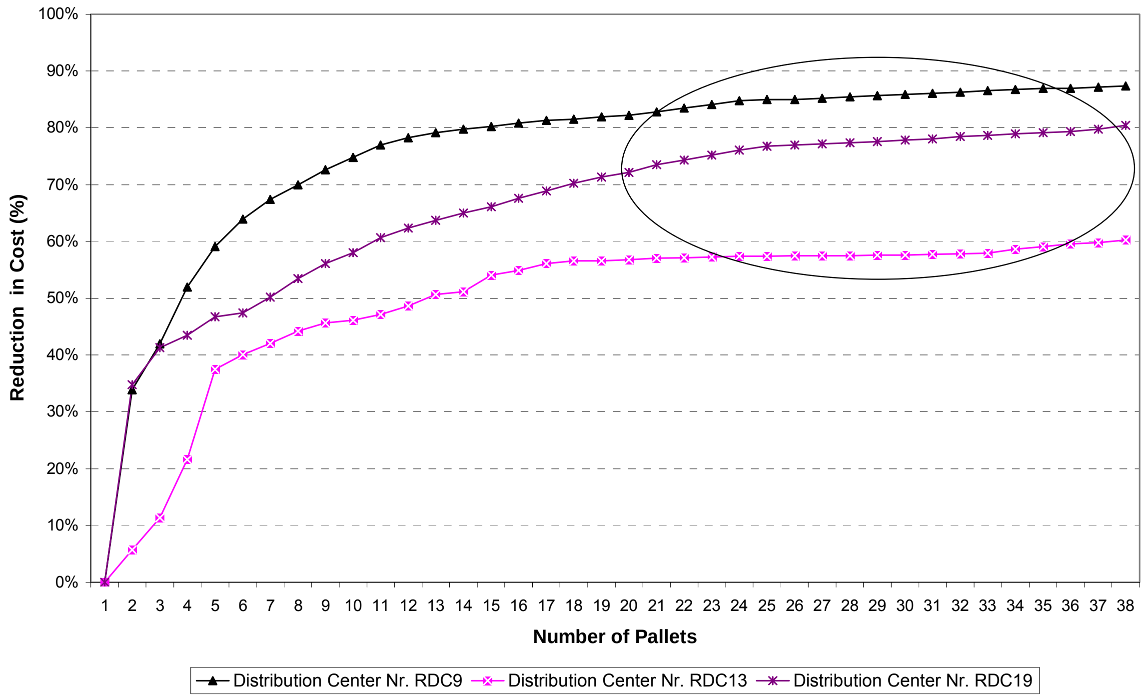

Figure 5. 19 Reduction in Transportation Cost

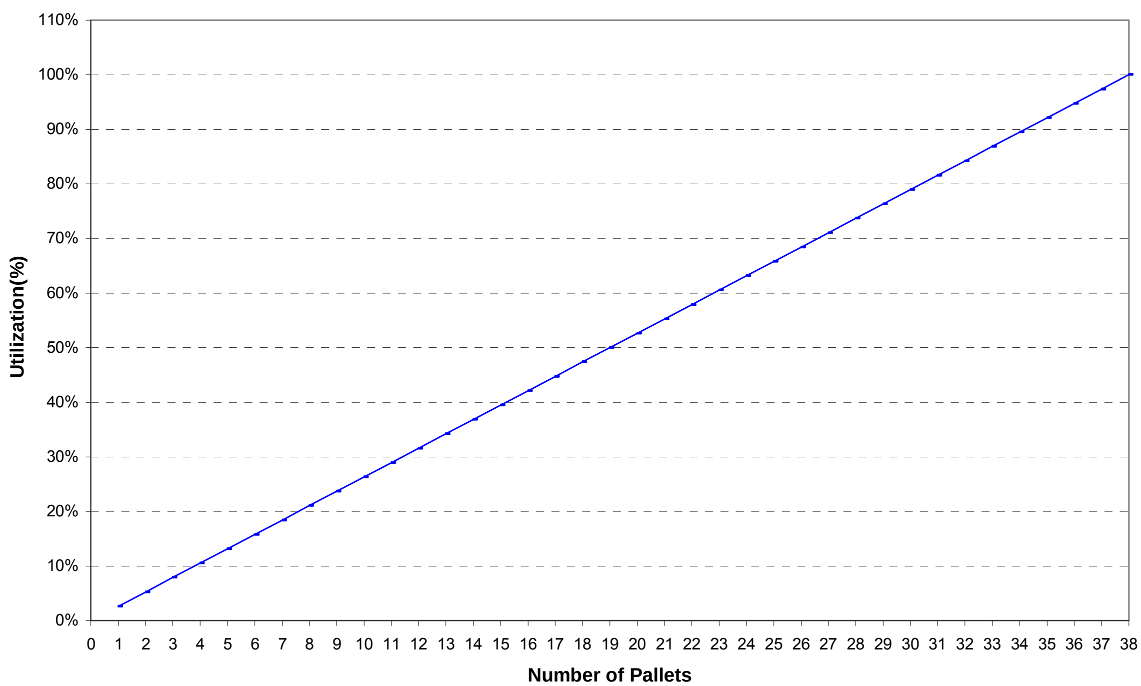

Figure 5. 20 Relationship between the Number of Pallets and the Truck Utilization

As mentioned above, one of the disadvantages of using coordination strategies is the increase in the average inventory level. When items are coordinated, some of them will be replenished earlier than if they were treated independently. This problem is named as residual stock [SPP98] and will be discussed in more details in the next section. Increasing the average inventory level is considered for redesigning the reorder point as safety stock. Then the uncoordinated strategy with consolidation concept (coordination strategy) is compared with the uncoordinated strategy with increasing reorder point (More Safety Stock). The idea is to use the residual stock as safety stock built into the reorder point. Based on this idea the equation for increasing the level of inventory from the coordination strategy, considered as safety stock instead of redesigning of the reorder point by adding safety stock, is created. The following are the experiments selected to carry out a comparison study for this purpose:

- Experiment ABC– Item Strategy (without Safety Stock) - (UCS- Expt 1)
- Experiment ABC-Item Strategy (with Safety Stock) - (UCS- Expt 2)
- Experiment ABC– Item (without Safety Stock) with ABC-Articles (Items) type Coordination Strategy (CS1-ABC-Expt1)
- Experiment ABC– Item (without Safety Stock) 4-Days Forecasted Demand Coordination Strategy (CS1-4D-Expt6)

The first strategy is designed without considering of the safety stock, the second strategy is designed with more consideration of the safety (Table 4.14), and the third and fourth strategies are coordination strategies of the first strategy (Table 5.1).

The results of all the strategies are compared and summarized in Table 5.10 and Table 5.11.

Table 5. 10 Improving Order Fill Rate of the Four Selected Experiments

Experiments	Improving Average Order Fill Rate (%)
CS1-4D-Expt6	46,19%
CS1-ABC-Expt1	38,90%
UCS-Expt 2	36,98%
UCS-Expt 1*	0,00%

* Base Experiment

Table 5. 11 Increasing Total Logistics Costs of the Four Selected Experiments

Experiments	Increasing Total Logistics Cost (%)
CS1-4D-Expt6	-0,98%
CS1-ABC-Expt1	31,44%
UCS-Expt 2	0,95%
UCS-Expt 1*	0,00%

* Base Experiment

The above tables show that, the coordination strategies can improve the service level better than redesigning the reorder point with more safety stock does. So it is recommended that to improve service level, coordination strategies should be used rather than increasing the safety stock policy. For example, the (CS1-4D-Expt6) coordination strategy improves the Order Fill Rate of (UCS- Expt 1) uncoordinated strategy by 46% without increasing the total logistic costs and in the same time the (UCS- Expt 2) uncoordinated strategy (More safety stock) improves the Order Fill Rate by 36% with increasing the total logistic costs. Therefore, instead of thinking of increasing the safety stock for improving the service level, more attention should be paid to applying coordination strategies.

5.3.2. Residual Stock Analysis

In this section the problem of increasing the stock level in distribution centers caused by consolidation concepts in coordination strategies is discussed. The increasing results when an item is reordered while it is still above its reorder point. This is because some other items in the distribution center will trigger the replenishment. The excess stock above the reorder point is known as ***residual stock*** [SPP98]. The residual stock must be taken into account because it adds safety stock above and beyond the usual safety stock included in the reorder point. All the used consolidation concepts cause this problem. Detailed investigations and analysis have been done and the main points are explored. Statistical analysis tests are performed to fit the residual stock distribution from different consolidation concepts. Therefore, many items from different distribution centers are selected and fitted by using the supported tool "Input Analyzer" of Arena 5.0 Software (Rockwell Software, [KSS02]). The results of the experiment coordination strategy experiments (3) and uncoordinated strategy “experiment ABC-Item strategy (minimize of transportation)” are taken as a base experiment for performing this analysis. Two distribution centers are also selected: RDC17 and RDC19. As discussed in the literature, Miltenburg and Silver [MS84] have found that in a periodic review system a normal distribution provides a reasonable fit to the distribution of residual stock. In this thesis, the continuous review with (s, S) control policy is used, and the best fit for residual stock for most consolidation concepts is found to be the normal distribution. For example, for an A-item using an ABC-Articles type Consolidation Concept, the best fit to the distribution of residual stock is normal distribution (Square Error: 0.014247) and the same item using (4-Days Forecasted Demand) consolidation concept, the best fit to the distribution of residual stock is exponential distribution (Square Error: 0.007835). Such distributions must be taken into account when establishing the reorder points (as safety stock).

The summarized results of the analyzed residual stock for both distribution centers are shown in Figure 5.21 and Figure 5.22.

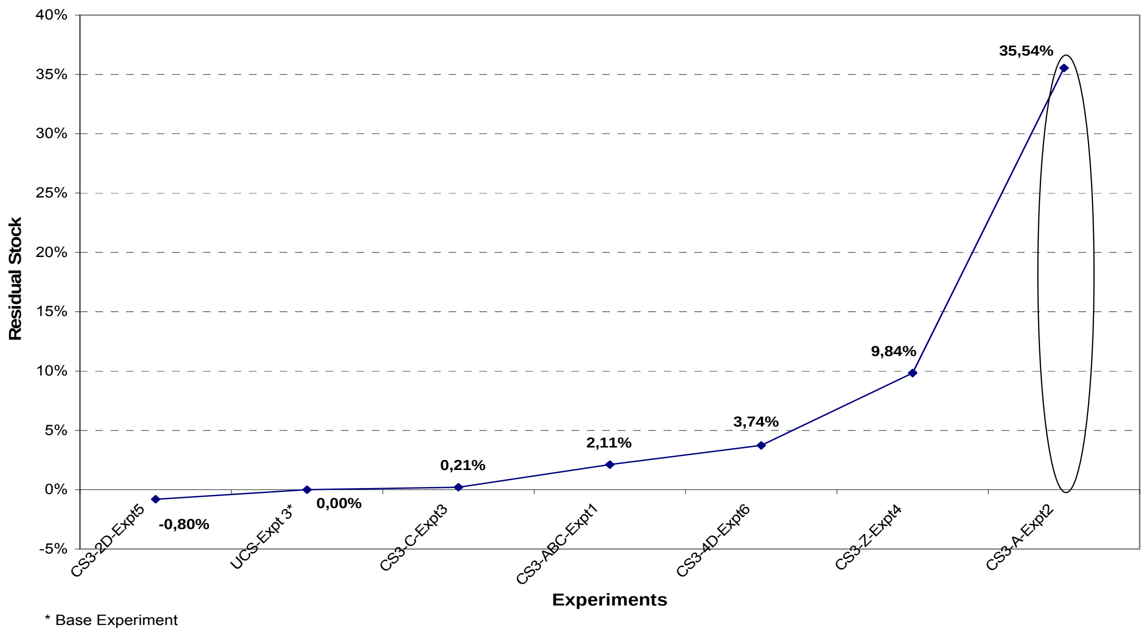

Figure 5. 21 Percentage of Increase in the Average Residual Stock by Each Consolidation Concept in RDC17 [A-Item]

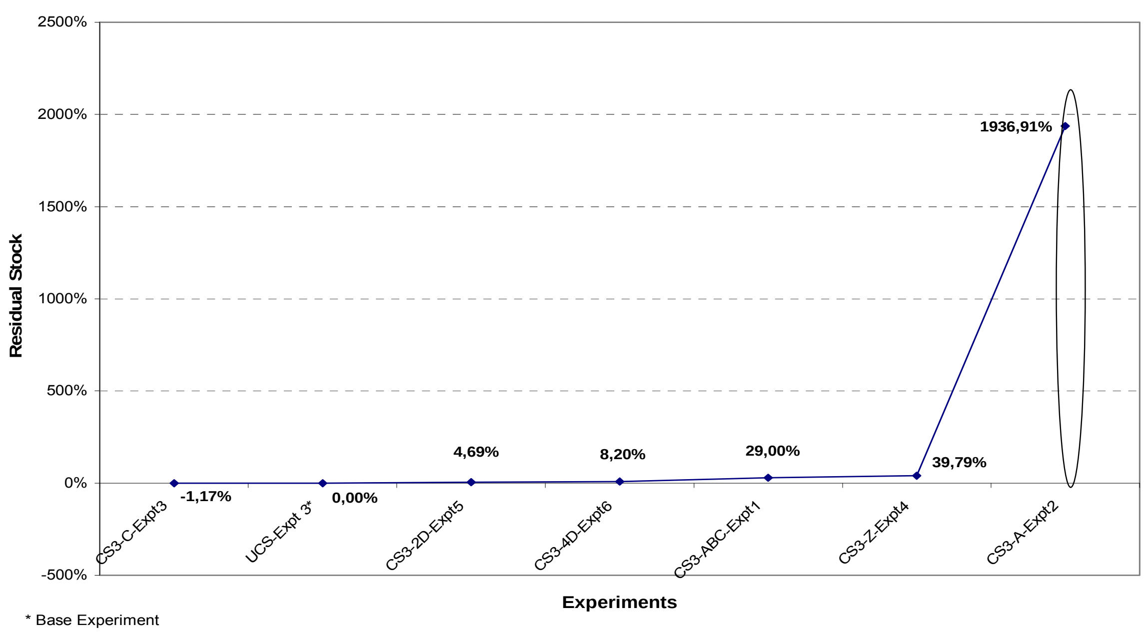

Figure 5. 22 Percentage of Increase in the Average Residual Stock by Each Consolidation Concept in RDC19 [A-Item]

The Residual stock chart of 4-Days Forecasted Demand consolidation concept for RDC19 is shown in Figure 5.23. The peak point of the residual is seen in the month of December because of the huge demand rate in this month. This proves that this consolidation concept can handle the seasonality of demand with perfect balance of residual stock.

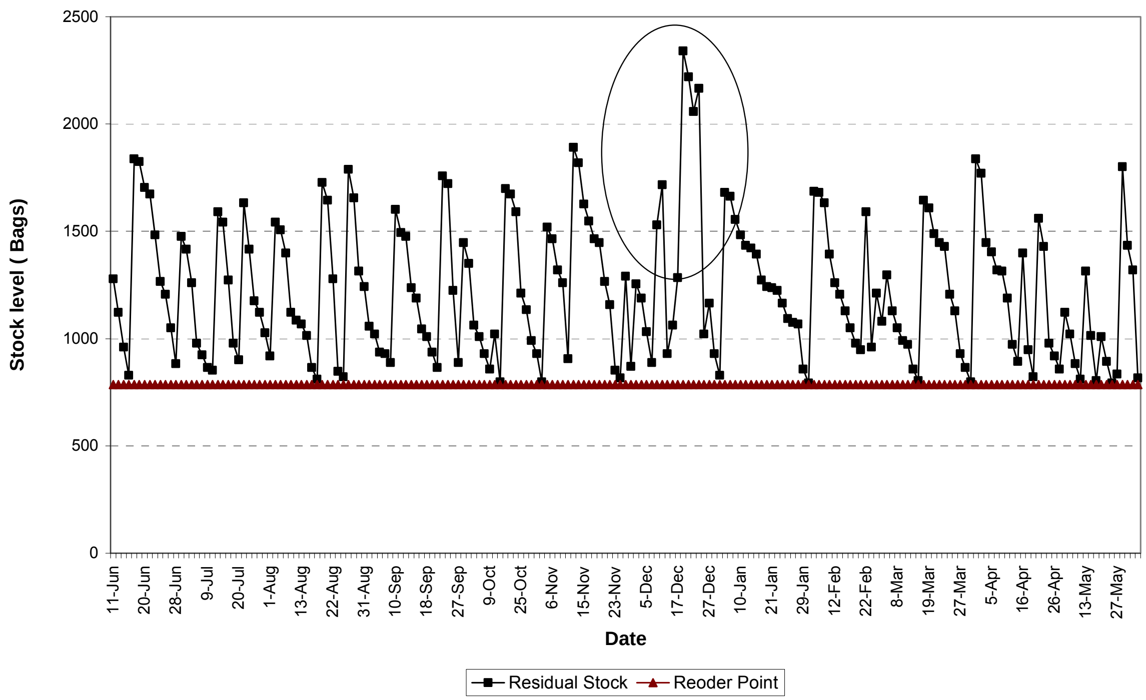

Figure 5. 23 Residual Stock and Reorder Point of A-Item Using 4-Days Forecasted Demand Consolidation Concept in RDC19

To control the residual stock, appropriate group replenishment should be selected. This depends mainly on the number of items selected for consolidation, the quantity of each item, and the average usage or demand rate. To show that, one fast moving high demand variability item (ZA- Item) in the above two distribution centers is selected. The residual stock of this item caused by two consolidation concepts (Z-Articles and A- Articles) is calculated and shown in Figure 5.24 and Figure 5.25, respectively.

In RDC19, the average residual stock of this item by using Z-Articles consolidation concept is less than that when using A-Articles consolidation concept is used. It is clear from due to the percentage of each item classification in this distribution. The A-Item percentage is 18% and Z-Item is 50%. This means that the number of consolidation items in Z-Articles consolidation concept *is more than* the number of consolidation items in the A-Articles consolidation concept and the consolidated quantity size of each item in Z-Articles consolidation concept *is lower than* the consolidated quantity size of each item in the A-Articles consolidation concept (Figure 5.24 and 5.25).

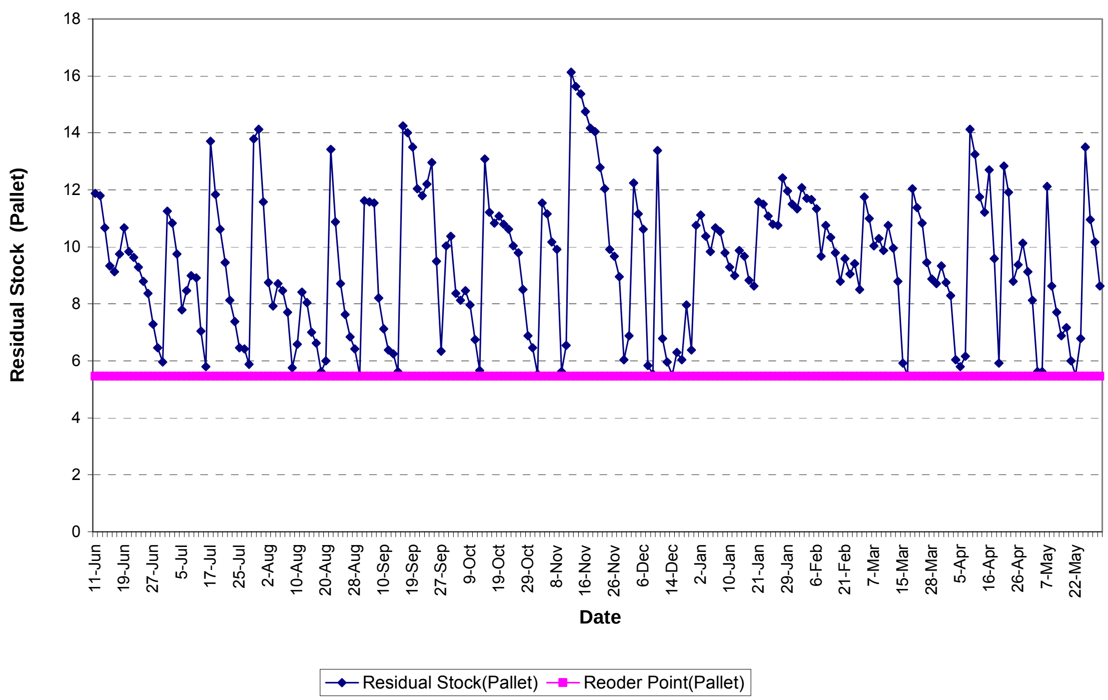

Figure 5. 24 Residual Stock of ZA Item Using (Z-Articles) Consolidation Concept in RDC19

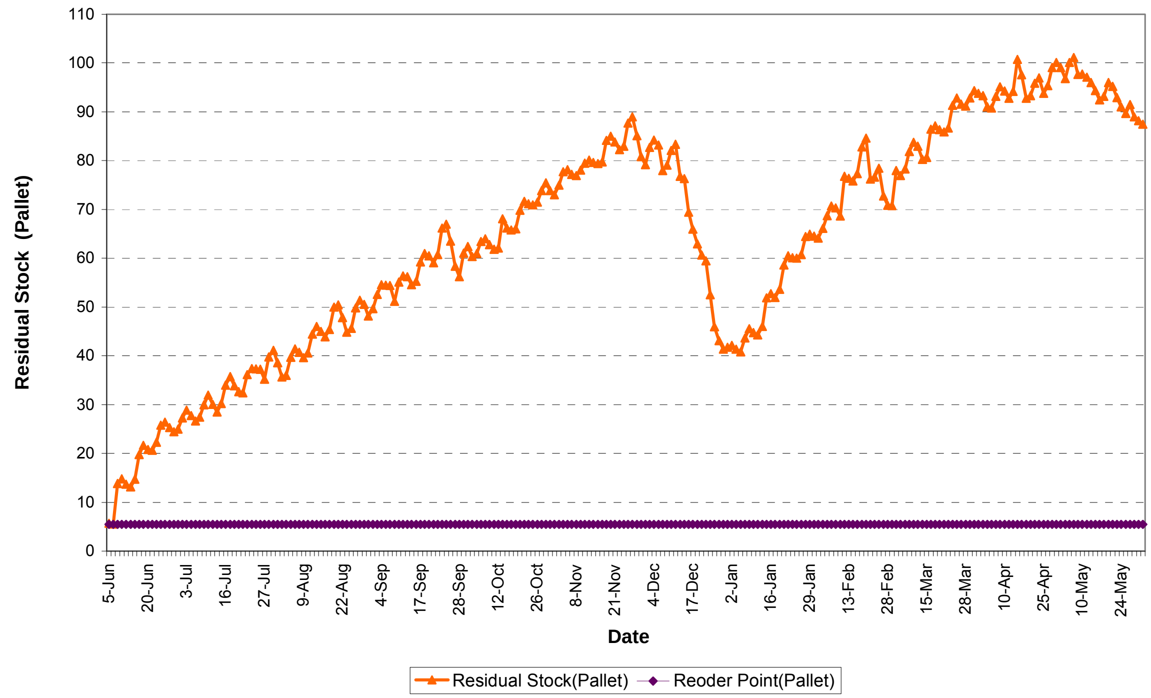

Figure 5. 25 Residual Stock of ZA Item Using (A-Articles) Consolidation Concept in RDC19

To explain the effect of consumption rate of each item on the residual stock, the average residual stock of the same item (ZA item) in the two distribution centers is compared and presented in the Figure 5.26. From this figure, the residual stock of this item caused by consolidation concepts at RDC17 is less than that at RDC19. This is due to the fact that the average demand rate of the item in RDC17 is greater than that in RDC19 (Avg. Demand = 3 pallets & Avg. Demand = 1.5 pallets, respectively). As mentioned in Chapter 3, the minimum quantity size of consolidation of each item is equal to one pallet. Therefore, the consolidated load in RDC17 is approximately 33% of the average demand rate whereas in RDC19 it is approximately 67% of the average demand rate.

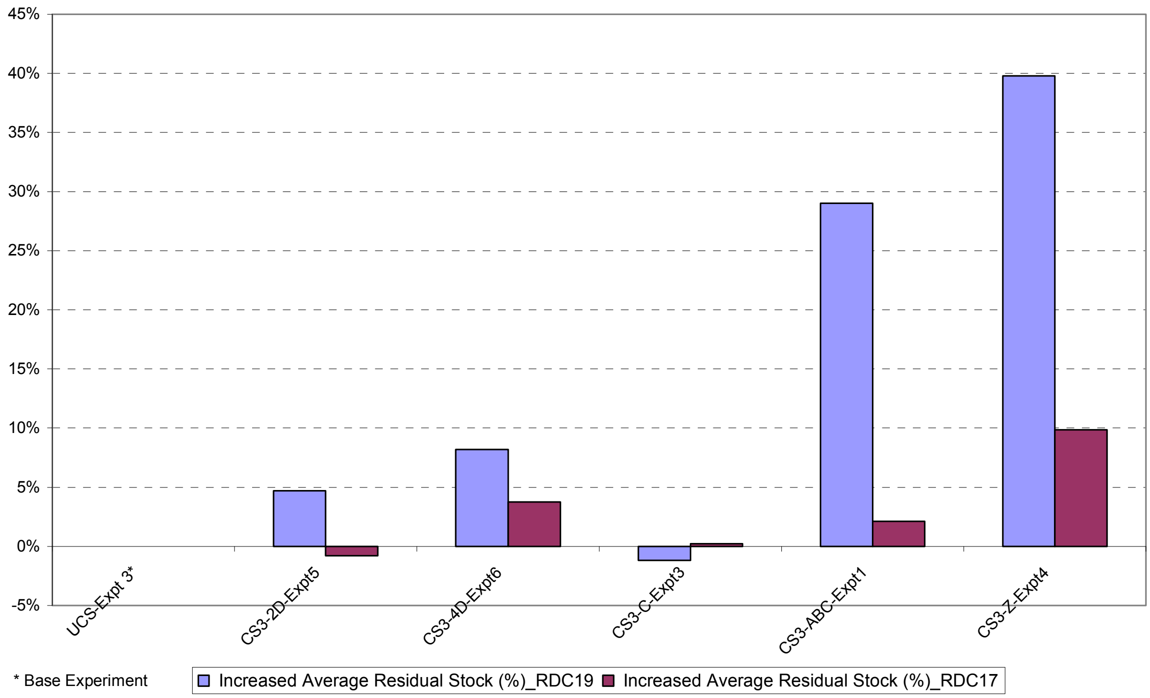

Figure 5. 26 Comparison of Increasing Average Residual Stock (%) of ZA-Item in Two Distribution Centers (RDC17 & RDC19)

One of the complex problems for controlling of the residual stock is the selection of the proper quantity of consolidation groups. The studied model (real Model); it is much more complex because the items are replenished from different suppliers. So, it is not easy to control the consolidation shipment size. To explain this problem, the percentage of supplying or replenishing A-Items from the three suppliers (Warehouses) to each distribution center is calculated and the average percentage of all distribution centers is estimated and presented in Figure 5.27.

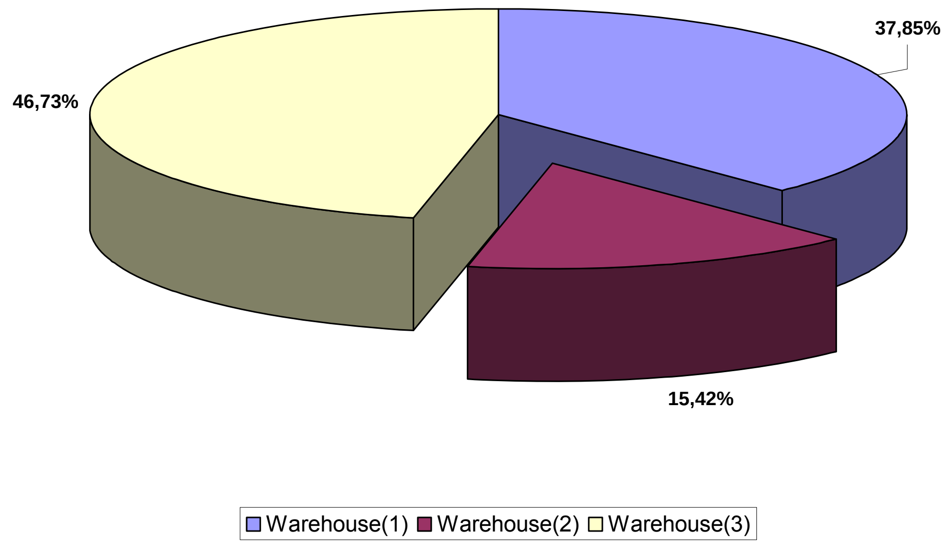

Figure 5. 27 Average Percentage of A-Item from Suppliers (Warehouses) to Distribution Centers

When more items are consolidated with a proper consolidation quantity size, the effect of residual stock will be reduced. This is due to the increase in the interval period time between replenishments of many items. Increasing the interval period between replenishments can reduce the number of replenishments, which finally reduces the average ending inventory levels.

5.3.3. Truck Utilization Analysis:

As mentioned in Chapter 3, the item classification consolidation concepts can guarantee that the replenishment quantities will generate a full truckload. From the results, all the Item classification consolidation concepts produce 100% utilization of truck. To show the effect of the coordination strategies on the utilization of truck, as it is done in the previous chapter, the truck utilization between the upstream locations and RDC15 for each coordination strategy with the 4-Days Forecasted Demand consolidation concept is presented in Figure 5.28.

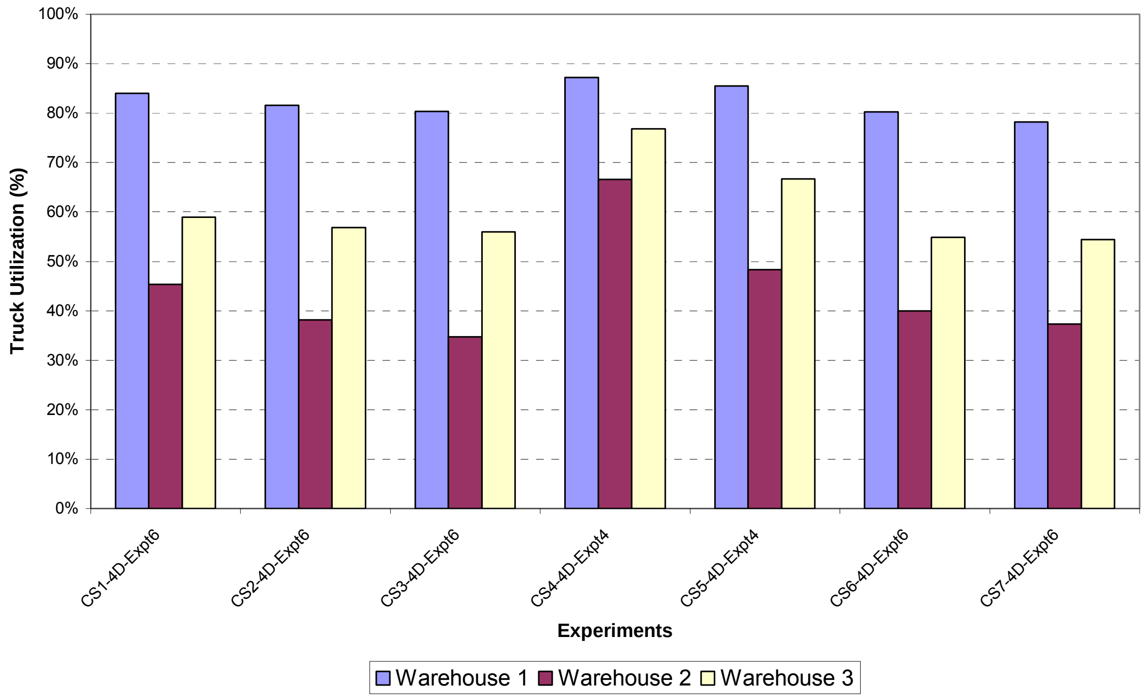

Figure 5. 28 Truck Utilization between Upstream Locations and RDC15

From Figure 5.28, it is clear that the truck utilization is improved by using the coordination strategies, which is 63% on the average. This figure is about 6% higher than that for the uncoordinated strategies (Figure 4.24 and 5.28).

Conclusion:

Regarding the analysis and investigation of the results, the following conclusions can be made:

- Classifications of items are very important for uncoordinated and coordination strategies. Therefore, developing new classifications for items that are considered more appropriate classification criteria should be constructed.
- N-Days forecasted demand concepts are better than Item classification consolidation concepts for designing effective coordination strategies.
- Interaction between the reorder point design and the consolidation concepts is remarkable. So more consideration of this interaction is powerful for designing good coordination strategies.
- Coordination strategies which use Item classification consolidation concepts raise the ending inventory very highly. While the Coordination strategies which use N-Days forecasted demand concepts reduce the ending inventory.
- Truck Utilization is yet not highly utilized by using the N-Days forecasted demand concepts.

6. Optimization of Coordination Strategies: Developing New ABC Classification

In this chapter, the distribution coordination strategies have been optimized based on the conclusions of the previous chapters. These conclusions are mainly regarding the improvement of item classification approaches which could be used in constructing an appropriate consolidation concept. Finally the appropriate consolidation concept can improve the measures of performance of the distribution coordination strategies. Therefore, in this chapter a new item classification approach is presented.

6.1. New ABC Classification Model:

As a conclusion from last chapters, the right selection of item classification (More frequent Items) is the key for getting the optimal coordination strategy. Therefore, a new ABC Classification has been developed to optimize system performance. The idea behind constructing this classification is to consolidate more ordered or frequent items rather than items with high consumption rate. The consolidation of more ordered items produces fewer replenishments that can finally reduce the inventory and transportation cost. The New ABC classification will be integrated with the Item classification consolidation concept to develop a new consolidation concept that could improve the effectiveness of the old item consolidation concept. The improvement in the systems performance by using this classification in item consolidation concept has been proved and presented in this chapter.

As mentioned above, the items are classified based on the number of orders for each item (order lines):

- A-Class: This class represents about 24 to 50% of the items carried in inventory and 75% of the total number of order lines.

- B-Class: This class represents about 10 to 17% of the items carried in inventory and 15% of the total number of order lines.
- C-Class: This class represents about 38 to 63% of the items carried in inventory and 10% of the total number of order lines.

As in the previous three classifications, the New ABC classification has been done for all the distribution centers based on the real demand data from the company. The New ABC classification of some distribution centers are exhibited in the following figures.

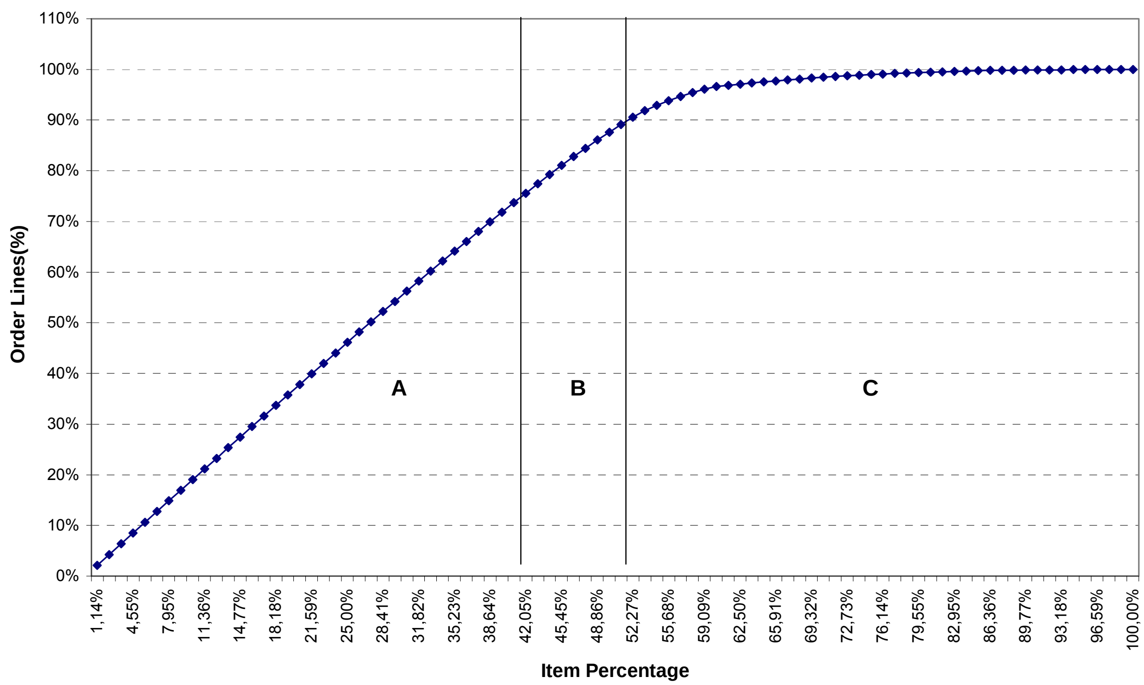

Figure 6. 1 ABC New Classification for LDC1

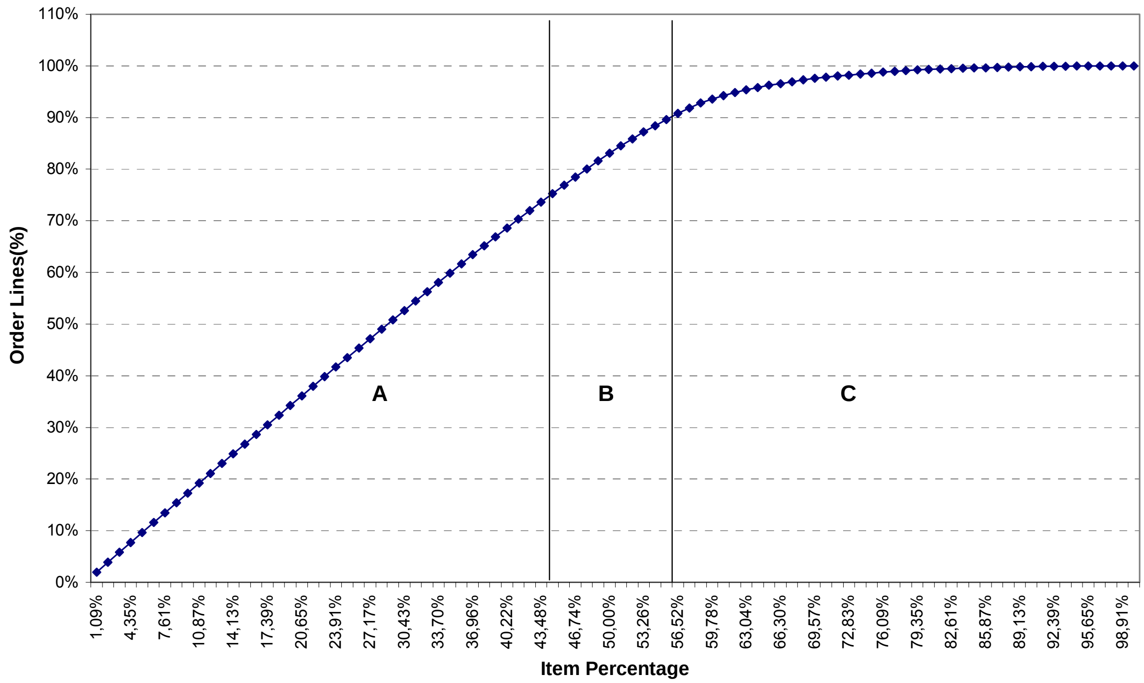

Figure 6. 2 ABC New Classification for LDC5

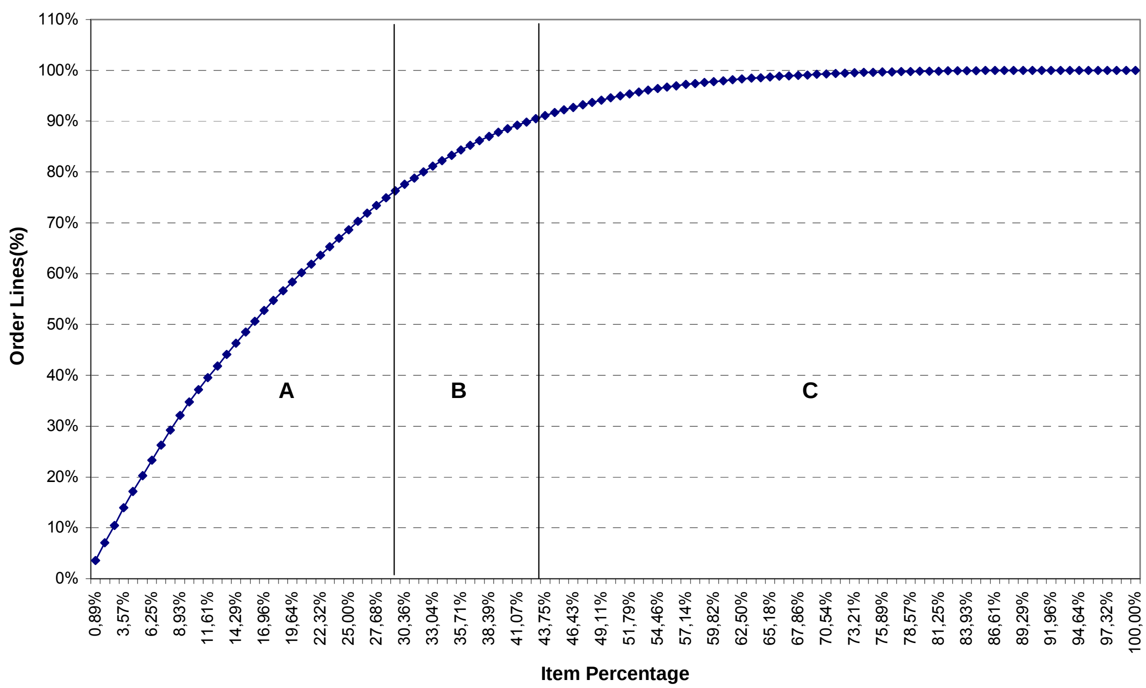

Figure 6. 3 ABC New Classification for RDC15

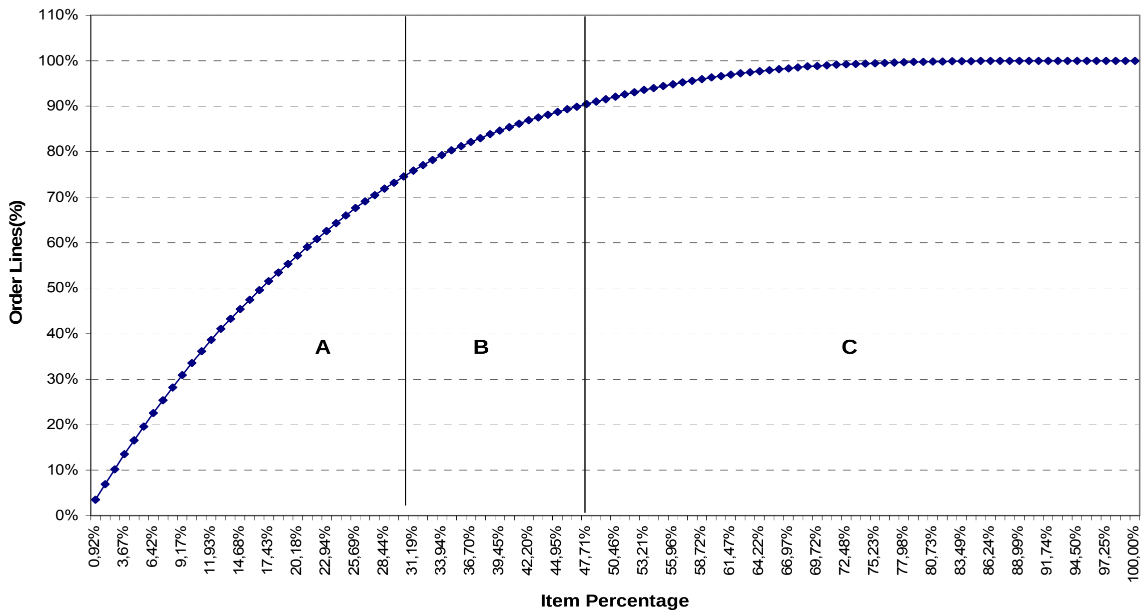

Figure 6. 4 ABC New Classification for RDC19

The percentage of items in each class for each distribution center is exhibited in Table 6.1.

Table 6. 1 Percentage of Items in each Class for each Distribution Center (New ABC Classification)

DC	A	B	C	Total
RDC1	30,19%	14,15%	55,66%	100,00%
RDC2	33,33%	15,74%	50,93%	100,00%
RDC3	31,86%	13,27%	54,87%	100,00%
RDC4	35,58%	14,42%	50,00%	100,00%
RDC5	34,55%	12,73%	52,73%	100,00%
RDC6	24,63%	12,69%	62,69%	100,00%
RDC7	29,82%	14,04%	56,14%	100,00%
RDC8	30,28%	11,93%	57,80%	100,00%
RDC9	28,70%	10,19%	61,11%	100,00%
RDC10	30,91%	13,64%	55,45%	100,00%
RDC11	27,52%	13,76%	58,72%	100,00%
RDC12	32,71%	13,08%	54,21%	100,00%
RDC13	32,74%	13,27%	53,98%	100,00%
RDC14	32,17%	13,04%	54,78%	100,00%
RDC15	28,57%	13,39%	58,04%	100,00%
RDC16	27,88%	15,38%	56,73%	100,00%
RDC17	28,80%	11,20%	60,00%	100,00%
RDC18	31,78%	13,08%	55,14%	100,00%
RDC19	30,28%	16,51%	53,21%	100,00%
LDC1	40,91%	10,23%	48,86%	100,00%
LDC2	40,70%	11,63%	47,67%	100,00%
LDC3	39,02%	13,41%	47,56%	100,00%
LDC4	49,38%	12,35%	38,27%	100,00%
LDC5	43,48%	11,96%	44,57%	100,00%

To show the difference between the old ABC and the New ABC classifications, the percentage of items in each class of the two classifications for all the distribution centers are illustrated in the following Figures:

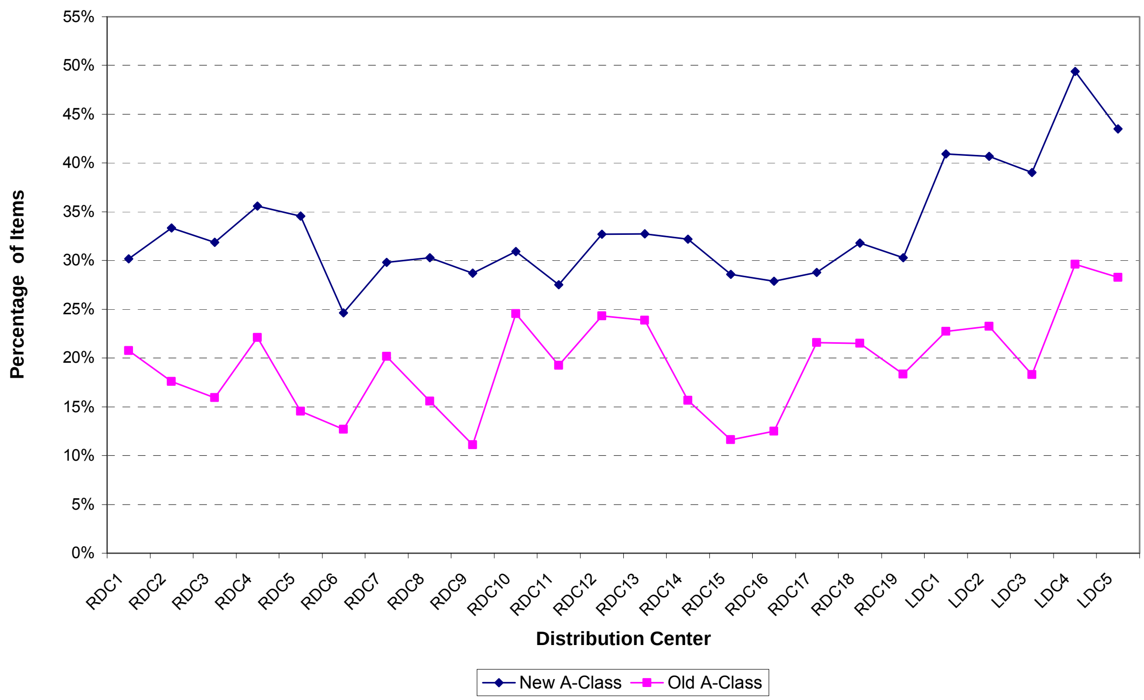

Figure 6. 5 Percentage of Items in A Class for each Distribution Center in Two Classifications

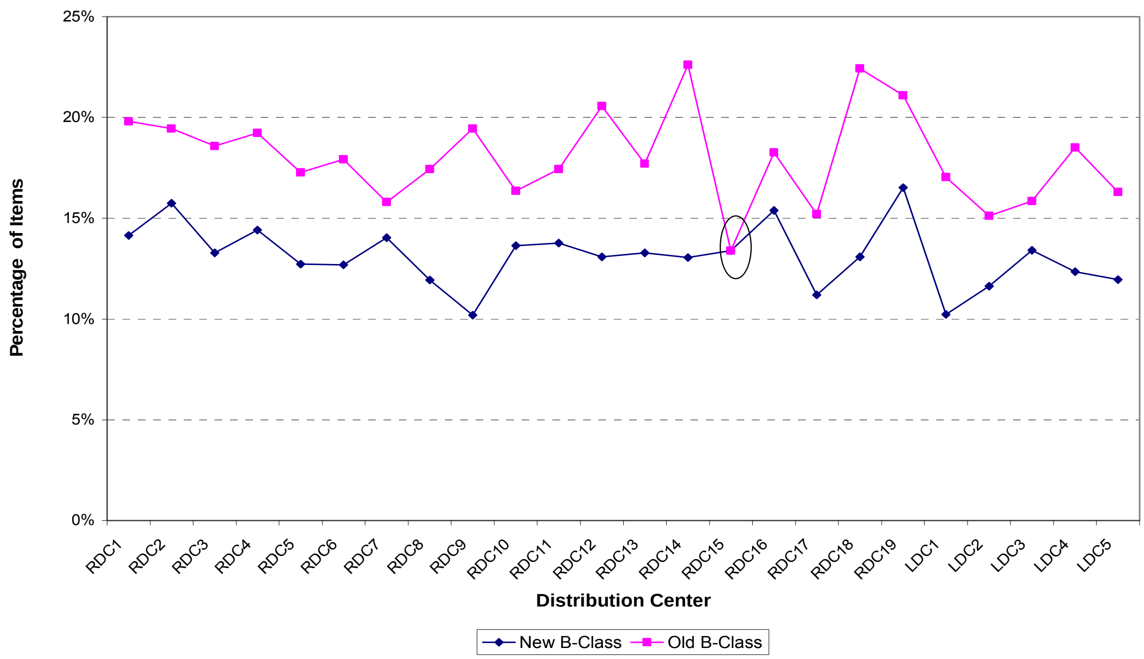

Figure 6. 6 Percentage of Items in B Class for each Distribution Center in the two Classifications

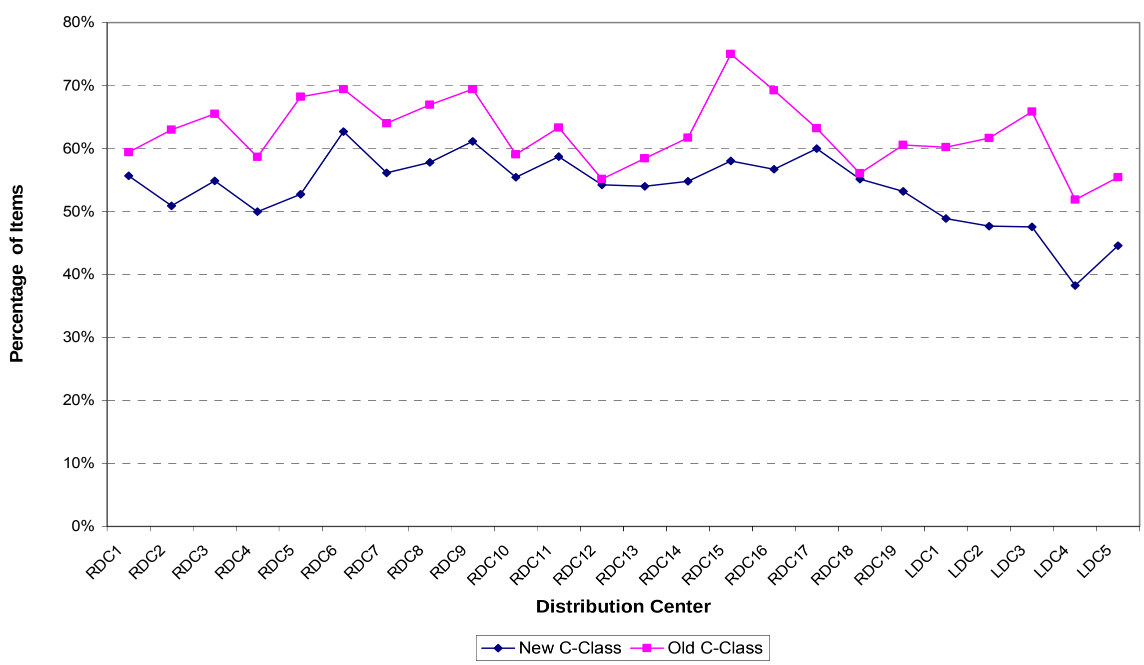

Figure 6. 7 Percentage of Items in C Class for each Distribution Center in the two Classifications

The average percentage of items in each class of the two classifications for all the distribution centers is shown in Figure 6.8.

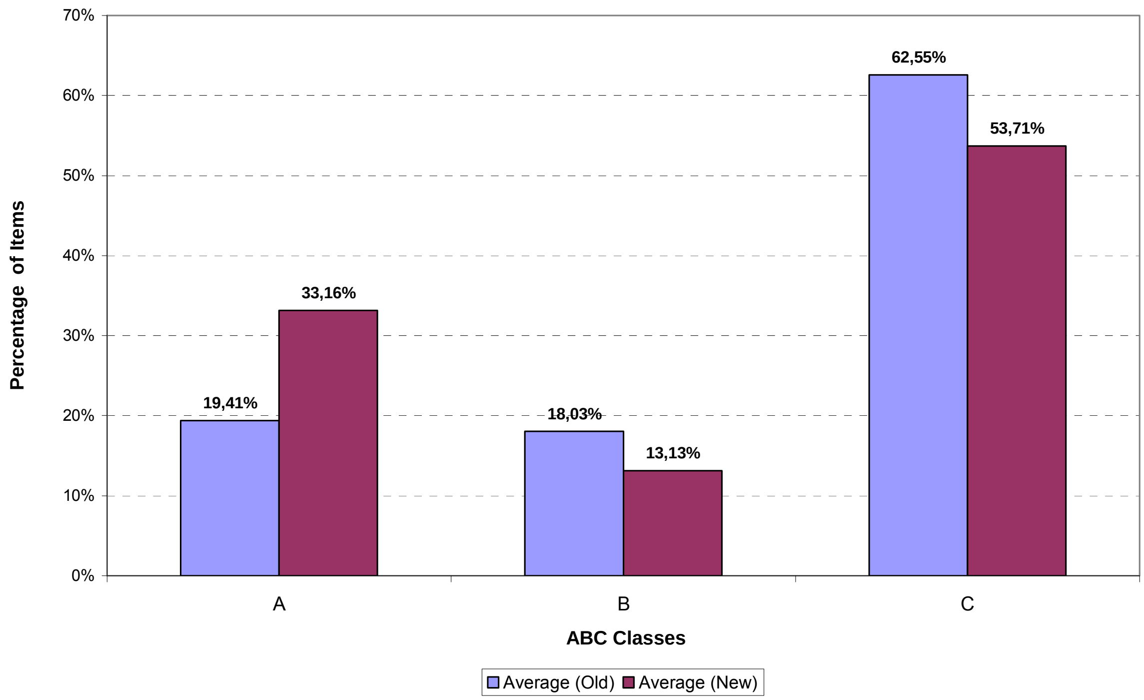

Figure 6. 8 Average Percentages of Items in each Class for the two Classifications

6.2. Experiments Designs

In these experiment designs, the New ABC classification has been used to design the control parameters (s, S) in uncoordinated strategies and Item classification consolidation concept in coordination strategies.

In this section, three general experiments are considered and conducted by implementing the developed simulation model as is the case in the previous chapters. All the assumptions and considerations used in the last two chapters are used in these experiments, too.

- UCS-N-Expt: Uncoordinated Strategy with new ABC classification experiment.

- CS-N-Expt: Coordination Strategy with new ABC classification experiment

6.2.1. Experiment New-ABC-Item Uncoordinated Strategy - (UCS-N-Expt):

Based on the New ABC Classification, the reorder point and the maximum inventory level for each item are designed. To estimate these two parameters the general equation (4.4) is used. Table 6.2 shows the number of days given for each parameter.

Table 6. 2 Reorder Point and Maximum Inventory Level for Each Item Class

New ABC Classification	s (Days)	S (Days)
A	4	10
B	6	10
C	10	15

As can bee seen in the above table and Table 4.5, the logic of designing the control parameters (s, S) in this strategy is same as in the uncoordinated strategy (Experiment ABC-Item Strategy, UCS- Expt 3) in Chapter 4. The reason for that is to enhance the importance of item classifications on the effectiveness of the distribution strategies.

6.2.2. Experiments New-ABC-Item Coordination Strategy (1) - (CS1-N-Expt):

The main goal of this experiment design is to prove that the coordination strategies are still better than uncoordinated strategies, even with a new ABC classification and also to show the effect of using the new ABC classification in the Item classification consolidation concept on the performance of the coordination strategies.

The New ABC Classification has been used to develop the following three new Item consolidation concepts. These three concepts are as follows:

1. Full Truck Load with New-ABC-Articles type.
2. Full Truck Load with New-A-Articles type.
3. Full Truck Load with New-C-Articles type.

In this experiments design, the Experiment New-ABC-Item Uncoordinated Strategy (UCS-N-Expt) is integrated with all the above consolidation concepts and also with two of the N-Days forecasted demand consolidation concepts to generate five new experiments. The name of each experiment strategy is described as follows:

1. Experiment New-ABC-Item Uncoordinated Strategy with New-ABC-Articles (CS1-N-ABC-Expt1)
2. Experiment New-ABC-Item Uncoordinated Strategy with New-A-Articles (CS1-N-A-Expt2)
3. Experiment New-ABC-Item Uncoordinated Strategy with New-C-Articles (CS1-N-C-Expt3)
4. Experiment New-ABC-Item Uncoordinated Strategy with 2-Days Forecasted Demand (CS1-N-2D-Expt4).
5. Experiment New-ABC-Item Uncoordinated Strategy with 4-Days Forecasted Demand (CS1-N-4D-Expt5).

As mentioned before, all the experiments are conducted by using the developed simulation model.

6.2.3. Experiments New-ABC-Item Coordination Strategy (2) - (CS2-N-Expt):

To prove the importance of item classification in consolidation and optimization of system performance, new experiments are designed and compared with old experiments to show how this new classification can optimize system performance.

As is the case in the previous experiment design, to design coordination strategies of these new experiments, the uncoordinated strategy (UCS- Expt 1) of Chapter 4 is integrated with the three new consolidation concepts developed in this chapter to generate three new experiments, which are:

1. UCS- Expt 1With New-ABC-Articles (CS2-N-ABC-Expt1).
2. UCS- Expt 1With New-A-Articles (CS2-N-A-Expt2).
3. UCS- Expt 1With New-C-Articles (CS2-N-C-Expt3).

The general structure of designing the two coordination strategies by using the new ABC classification is summarized in Table 6.3.

Table 6. 3 General Structure of Coordination Strategies Design Using the New ABC Classification

Expt-Name	Uncoordinated Strategy Expt.		Consolidation Concept				
	UCS-N-Expt	UCS- Expt 1	New-ABC	New-A	New-C	2D	4D
CS1-N-Expt	✓	-	✓	✓	✓	✓	✓
CS2-N-Expt	-	✓	✓	✓	✓	-	-

✓	Integrated
-	Not Integrated

6.3. Experimental Simulation Results and analysis

In this section, all the simulation results for one year from the uncoordinated and two coordination strategies are presented and analyzed.

6.3.1. Simulation Results and analysis of UCS-N-Expt & CS1-N-Expt Strategies

Many results have been collected and analyzed. For comparing the results, the uncoordinated strategy has been taken as a base experiment. The same measures of performance used in the last two chapters are selected with the same criteria of comparison. These measures of performance of the experiments are shown in Table 6.4 and Figure 6.9.

Table 6. 4 Measures of Performance for Each Coordination Strategy and the Base Strategy Based on Ascending Order of Average Order Fill Rate

Experiments	TTC	TIHC	TLC	AOLFR	AOFR
CS1-N-4D-Expt5	$8.088.056,27	$346.100,59	$8.434.156,86	99,13%	91,60%
CS1-N-A-Expt2	$10.285.458,75	$4.030.751,80	$14.316.210,55	99,40%	90,50%
CS1-N-ABC-Expt1	$8.433.566,17	$2.072.658,89	$10.506.225,06	98,99%	87,66%
CS1-N-2D-Expt4	$8.127.166,90	$351.701,64	$8.478.868,54	96,59%	66,39%
CS1-N-C-Expt3	$12.034.021,75	$6.535.079,61	$18.569.101,36	96,35%	62,60%
UCS-N-Expt*	$8.130.739,05	$353.766,68	$8.484.505,73	96,30%	62,20%

* Base Experiment

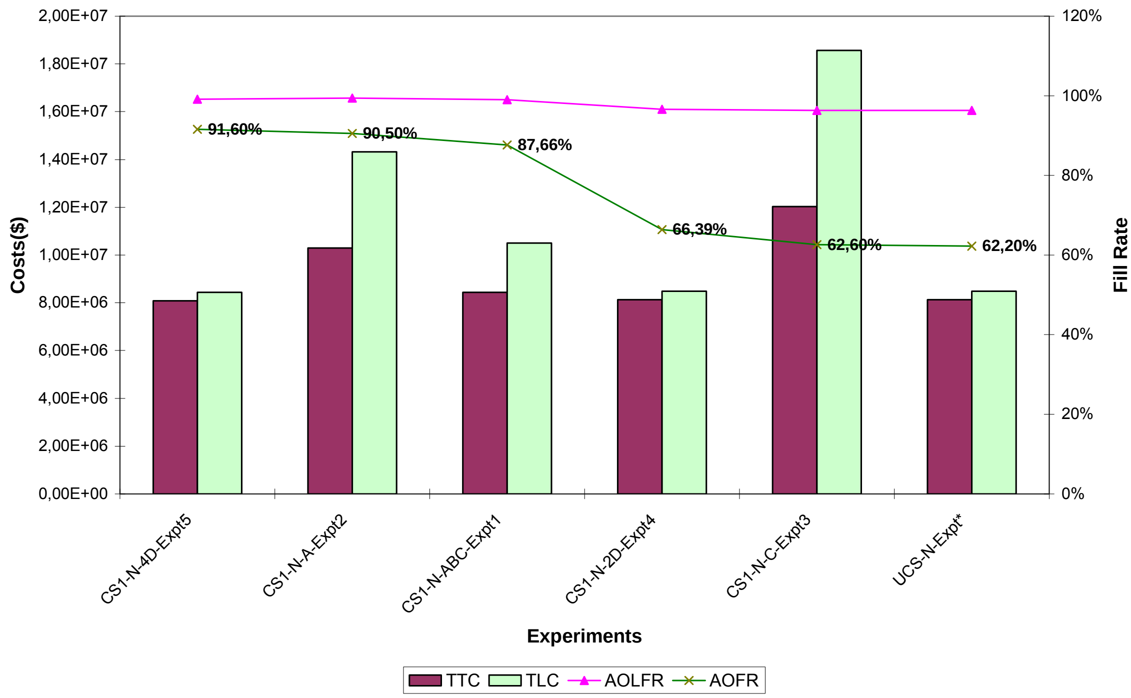

Figure 6. 9 Measures of Performance for Each Strategy Based on Ascending Order of Average Order Fill Rate

The percentage of improved average order fill rate and increased total logistics costs are calculated using the two equations (5.1) and (5.2) and are presented in Figure 6.10 and Figure 6.11, respectively.

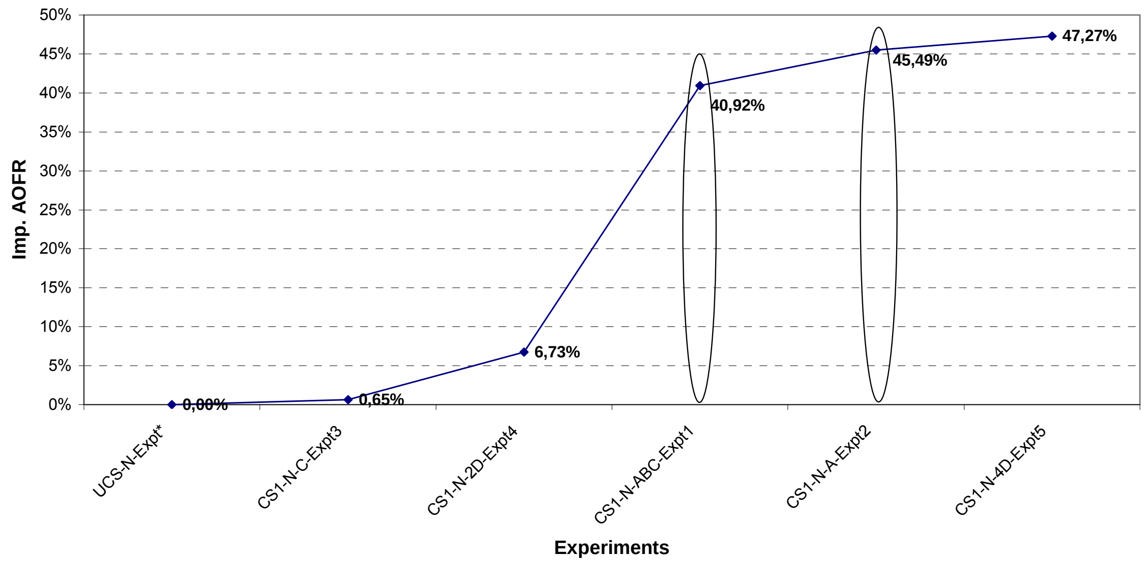

Figure 6. 10 Percentage of Improved Order Fill Rate by each Coordination Strategy

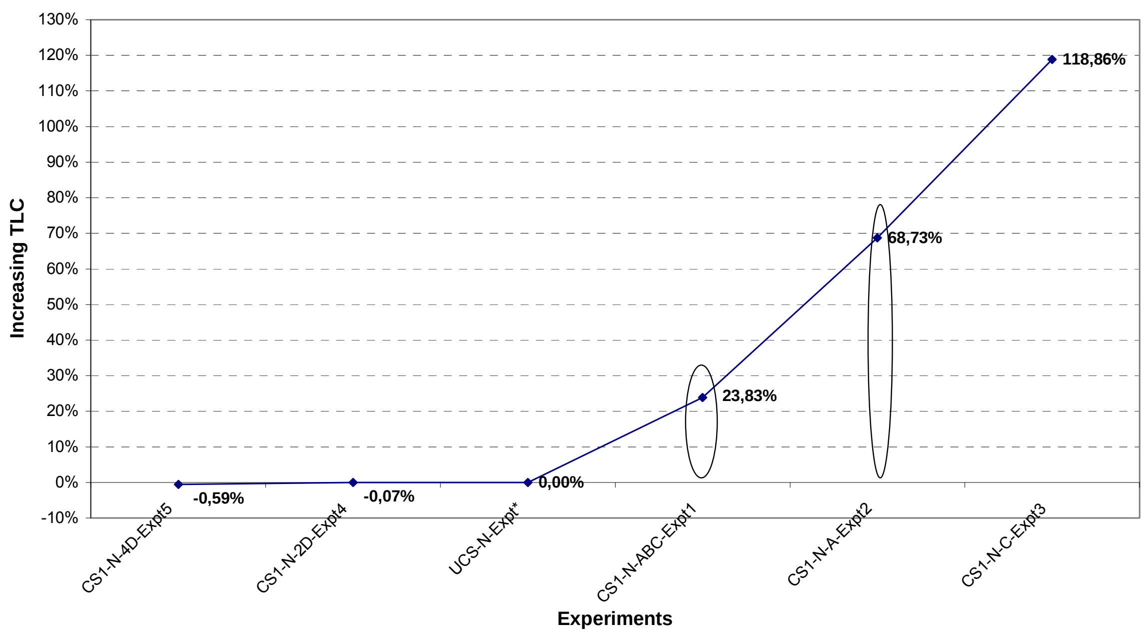

Figure 6. 11 Percentage of Increased Total Logistics Costs by Each Coordination Strategy

The following findings are collected from the previous figures:

- Coordination strategies still perform better than the uncoordinated strategies.
- In all the six experiments the coordination strategies using the 4-Days Forecasted Demand and the ABC-Articles consolidation concepts are the optimal strategies for improving the system performances.
- With respect to the AOFR, CS2-N-A-Expt2 coordination strategy using the A-Articles consolidation Concept is an attractive strategy for improving service level as compared specially with the ABC-Articles consolidation concept (Figure 6.10). This can be justified by the fact that the A-items type is more critical and sensitive in the new ABC classification than in the old ABC classification. To explain this better, a comparative study between two uncoordinated strategies is done. These two strategies are UCS-N-Expt and UCS- Expt 3. The selected strategies have the same design as the control parameters (s, S), as mentioned and explained at the beginning of this chapter. From the comparative study (Table 6.5), it was clear that under this design of parameters the UCS- Expt 3 performs better than UCS-N-Expt. This is due to the inappropriate design of s parameter for A items in the new classification (only 4 Days). A-items are more frequent in the new classification, therefore additional safety stock should be given for this item type.

Table 6. 5 Measures of Performance for the Selected Strategies

Experiments	TTC	TIHC	TLC	AOLFR	AOFR
UCS-N-Expt	$8.130.739,05	$353.766,68	$8.484.505,73	96,30%	62,20%
UCS-Expt 3	$8.125.338,06	$344.206,49	$8.469.544,55	98,17%	77,19%

- In the new ABC classification, C-Article consolidation concept is not attractive for constructing a coordination strategy; especially for improving the service level. It also increases the logistics cost by more than two times that of the uncoordinated strategy (Figure 6.11). Because here the slow moving items are consolidated and hence both the transportation and inventory costs are increased with no considerable improvement in the service level. So, it is not recommended to use this concept in a coordination strategy.

- By using this new classification of consolidation, there is a large percentage increase in the order fill rate and a low percentage increase in the total logistic costs as compared with all the results in Chapter 5. For example, in these experiments, the average order fill rate is improved by using the ABC-Articles consolidation concept by approximately 41% and the total logistic costs is increased by only approximately 24%. The maximum improvement in average order fill rate in all the experiments in Chapter 5 using the ABC-Articles consolidation concept was approximately 39% and the total logistics costs is increased by approximately 31% (Figure 5.12 and 5.13). This means that the new ABC classification classifies the items by better criteria for classification (Order lines).

6.3.2. Simulation Results and analysis of CS2-N-Expt Strategy

After the simulation run, the results for one year are collected. The measures of performance of the new experiments are compared with the results of the first coordination strategy experiments (CS1-Expt) of Chapter 5. These experiments integrate the same uncoordinated strategy (UCS-Expt 1) but with different Item consolidation concepts (Table 5.1 and Table 6.3). The comparison is shown in Table 6.6 and Figure 6.12.

Table 6. 6 Measures of Performance for the Selected Strategies Based on Ascending Order of Average Order Fill Rate

Experiments	TTC	TIHC	TLC	AOLFR	AOFR
CS2-N-ABC-Expt1	$8.355.320,89	$1.871.855,24	$10.227.176,13	98,96%	87,14%
CS1-ABC-Expt1	$8.687.533,81	$2.341.572,03	$11.029.105,84	98,74%	84,82%
CS2-N-A-Expt2	$9.568.005,11	$3.037.783,65	$12.605.788,76	98,85%	80,90%
CS1-C-Expt3	$11.510.425,29	$5.717.147,31	$17.227.572,60	97,31%	68,04%
CS1-A-Expt2	$10.639.802,17	$4.429.948,84	$15.069.751,01	97,55%	67,50%
CS2-N-C-Expt3	$11.691.301,93	$5.996.524,89	$17.687.826,82	96,74%	63,73%
UCS-Expt 1*	$8.114.944,57	$276.000,10	$8.390.944,67	96,44%	61,06%

* Base Experiment

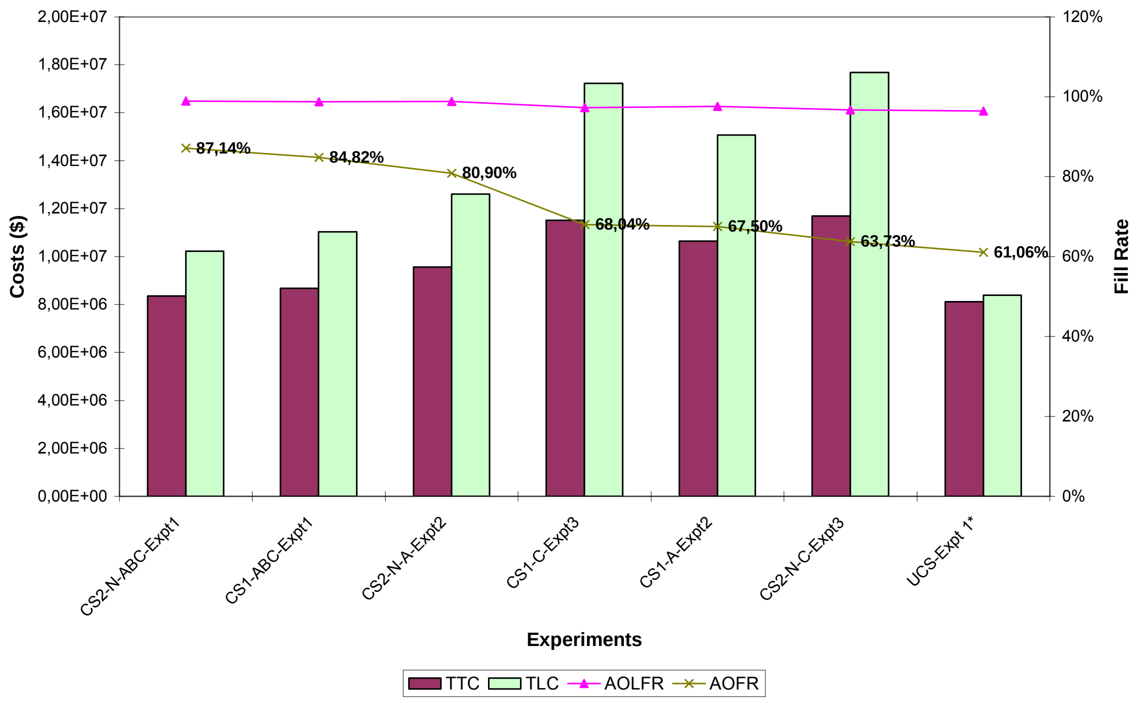

Figure 6. 12 Measures of Performance for the Selected Strategies Based on Ascending Order of Average Order Fill Rate

For comparison the percentage of improved order fill rate and increased total logistics costs of each experiment are calculated using equations (5.1) and (5.2) and are shown in Figures 6.13 and 6.14.

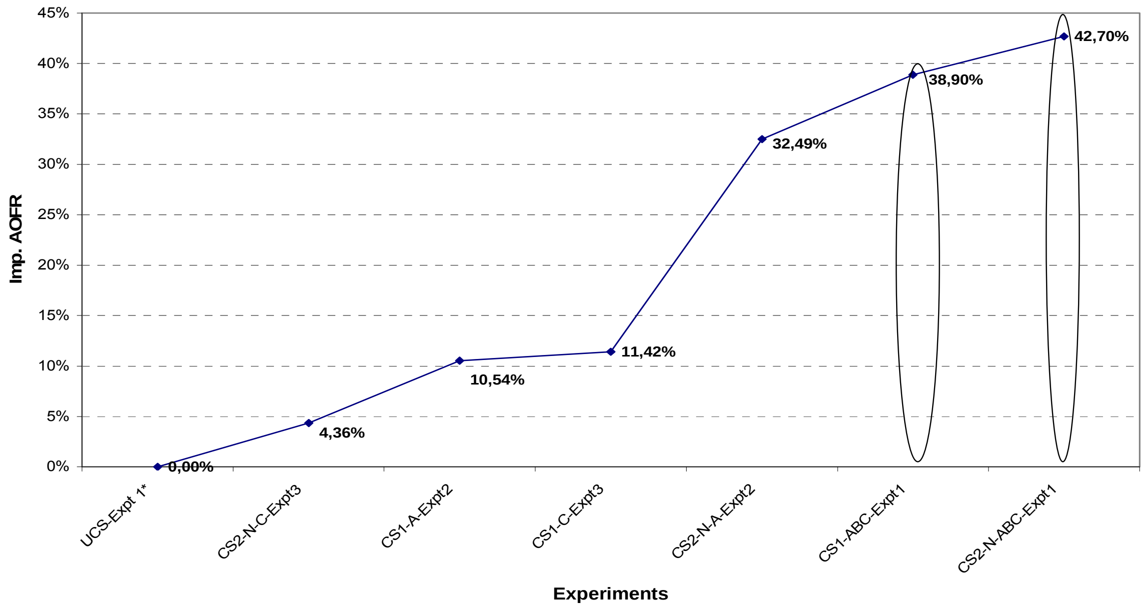

Figure 6. 13 Percentage of Improved Order Fill Rate by the Selected Coordination Strategy

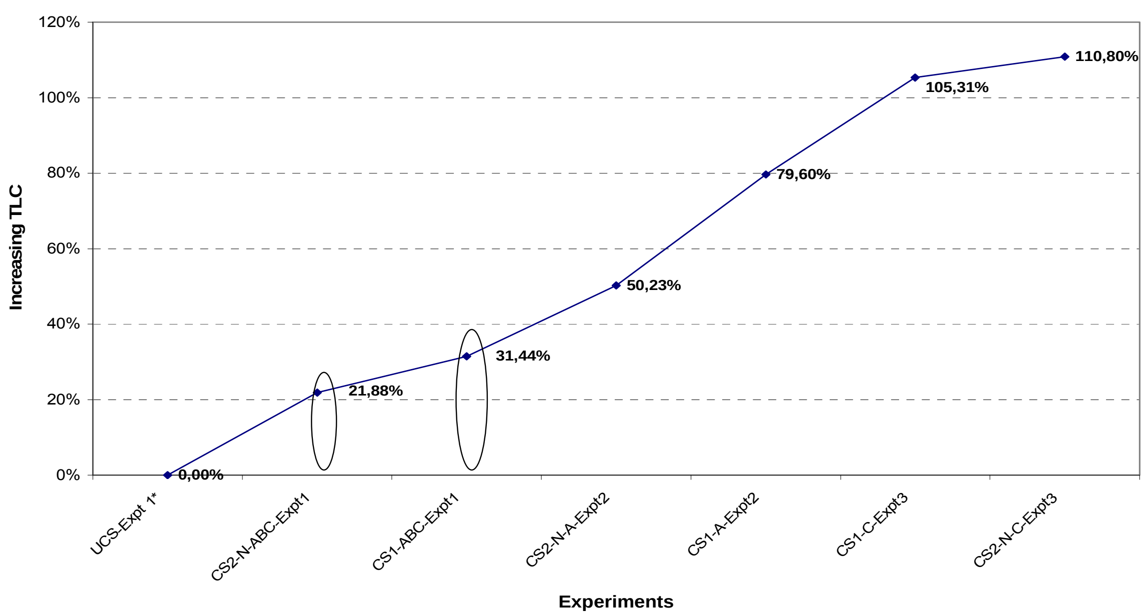

Figure 6. 14 Percentage of Increased Total Logistics Costs by the Selected Coordination Strategy

The number of replenishments for each distribution centre using the two consolidation concepts (ABC-Articles & New-ABC-Articles) are also calculated and shown in Figure 6.15.

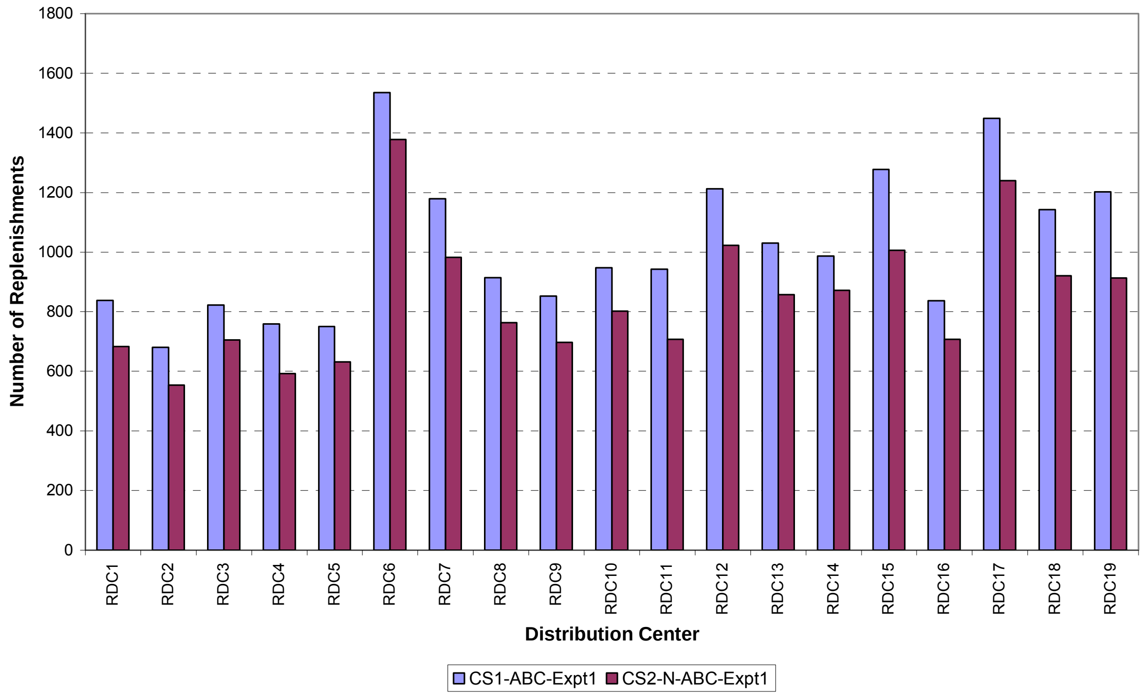

Figure 6. 15 Number of Replenishments for Each Distribution Center using the two Different Consolidation Concepts

- The results in the previous tables and figures show that the new ABC classification can improve system performance better than the old ABC classification.
- The percentage of improved Order fill rate is higher and the percentage of increased total logistics costs is lower when using the new classification, this is clear especially in ABC-Article consolidation concept. The percentage of improvement in the order fill rate of the new classification is approximately 4% higher than that in the old classification, and the percentage of increase

in the total logistics costs of the new classification is approximately 10% lower than that in old classification (Figures 6.13 and 6.14).

- The new classification is more attractive for consolidation than the other two classifications (ABC & XYZ) of Chapter 4 when the system performance is being optimised. This is due to the fact that consolidation with more frequent items (A items type) is better than that with high consumption rate items. This is specifically true when most frequent items are those same items with high variability.
- It is clear that the consolidation with more frequent ordered items could further reduce the transportation costs and the inventory costs (Table 6.6)
- Consolidation with more frequent ordered items can mainly reduce the number of replenishments; this has effect both on the transportation and inventory costs (Figure 6. 15).
- The residual stock of the new ABC classification is less than that of the old ABC classification. This could be justified by two reasons: the first reason is that the interval period between two replenishments is increased. This could be seen from the reduction in the number of replenishments, which in-turn reduces the number of periods that another item is replenished when it is still above its reorder point (residual stock). The second reason is the difference in percentage of items for each class (Table 6.7) in the two classifications. This percentage affects the consolidation quantities which play an important role for reducing the residual stock.

Table 6. 7 Average of Percentage of Item in Each Class

Classification Type	A	B	C
New Classification	**33,16%**	**13,13%**	**53,71%**
Old Classification	**19,41%**	**18,03%**	**62,55%**

* The average of all Distribution Centers

- As can be seen from the above table, the percentage of items in A-Class is higher in the new ABC classification. This gives more opportunity to consolidate more items with small consolidation shipment size, which reduces the residual stock.

- To avoid the effect of the differences in percentage of items in the two classifications for comparison and to prove that the new ABC classification performs better than the old classification, the two experiments were conducted for one distribution centre. In these two experiments, the A-Articles (Items) type consolidation concept is selected. The designs of these experiments are the same as those of “CS2-N-A-Expt2” and “CS1-A-Expt2” strategies (Table 5.1 and Table 6.3). In this distribution centre, the numbers of items of A-class (=36 items) for both classifications are same. After running the simulation, the results are analysed, compared, and presented in Table 6.8 and Table 6.9.

Table 6. 8 Measures of Performance and Comparisons Results of the two Experiments for RDC17

Experiments	TTC	TIHC	TLC	AOLFR	AOFR
CS2-N-A-Expt2	$205.302,76	$77.392,60	$282.695,36	98,86%	81,26%
CS1-A-Expt2*	$231.839,36	$109.999,96	$341.839,32	98,35%	78,29%

Table 6. 9 Comparisons of Measures of Performance of the two Experiments for RDC17

Experiments	Reduction inTLC	Improving in AOFR
CS2-N-A-Expt2	17,30%	3,80%
CS1-A-Expt2*	0,00%	0,00%

* Base Experiment

- As a conclusion from the Table 6.8 and Table 6.9., it is clear that the A-Articles type consolidation concept using new ABC classification performs better in all the terms of measures of performance. For example, the AOFR of CS2-N-A-Expt2 experiment is approximately 4% higher than that in the

CS1-A-Expt2 experiment and the TLC of CS2-N-A-Expt2 experiment is approximately 17% lower than that in the CS1-A-Expt2 experiment.

- For more explanation, using the results of the above two experiments (CS2-N-A-Expt2" & CS1-A-Expt2), of RDC17, the total residual stock for one year of an item is calculated and shown in Table 6.10. This item is the A-item type in the two ABC classifications.

Table 6. 10 Residual Stock of the A-item in the two Classifications

Experiments	Total Residual Stock (Pallets)
CS2-N-A-Expt2	2356
CS1-A-Expt2*	2721

* Base Experiment

- From the Table 6.10, it is clear that the residual stock of the A-item is reduced more than 13% by using the new ABC classification.

Conclusion:

Based on the analysis and investigations of the results, the following conclusions can be made:

- All the conclusions of the last chapter have been concluded by the results and analysis of this chapter.
- These results show the importance of the item classification and the effect of this classification on system performance in the supply chain.
- The new ABC classification is proved to be an attractive classification for constructing an appropriate consolidation concept.
- Using of the new ABC classification in constructing the consolidation concept improves all the systems performance.
- It is clear that the implementation of the new ABC classification could further reduce the inventory levels (residual stock), however, an increase in the inventory stock is observed.
- An attractive approach that can control the highly increasing inventory stock and that can also help the N-Days forecasted demand concept to improve truck utilization is presented in the next chapter. This approach can synchronize and coordinate inventory and transportation decisions by using information sharing technology.

7. Optimization of Coordination Strategies Using Vendor-Managed Inventory (VMI) Programs

7.1. VMI-Programs Model:

Vendor-managed inventory (VMI) is a supply-chain approach where the supplier is authorized to manage inventories of stock-keeping units at downstream locations. In VMI, distortion of demand information (known as the bullwhip effect) transferred from the downstream supply-chain location (e.g., retailer) to the upstream location (e.g., supplier) is minimized, stockout situations are less frequent, and inventory-carrying costs are reduced. Furthermore, a VMI supplier has the liberty of controlling the downstream resupply decisions rather than filling orders as they are placed. Thus, the approach offers a framework for synchronizing and coordinating inventory and transportation decisions [CL00].

Vendor managed inventory (VMI) is an important coordination initiative. In VMI, the vendor (supplier) is responsible for managing inventories at retailers using advanced online messaging and data-retrieval systems [AF98], [Par96], [SM98]. Reviewing the retailer's inventory levels, the supplier makes decisions regarding the quantity and timing of replenishment. This requires that inventory information at the retailer should be accessible to the supplier. As a result, the approach is gaining more attention and application as new information technology like the electronic data interchange (EDI) is improving and the cost of information sharing is decreasing. Cetinkaya and Lee [CL00], Axsäter [Axs00], and Cheung and Lee[CL02] give more detailed description and discussion of this approach, shipment consolidation and related literature

As mentioned in Chapter 3, a VMI simulation model has been constructed. This model is be implemented in this chapter for conducting all the designed experiments. The VMI model considers the warehouses as a supplier (vendor) and the distribution centres as retailers. Unlike the previous simulation models the inventory decisions and the consolidation decisions are taken at warehouses based on the information obtained from distribution centres.

The warehouse observes a sequence of random demands from a group of distribution centres located in a given geographical region as they are realized. Ideally, these demands should be shipped immediately. In this model, the time definite delivery (TDD) agreements contracts are used. These agreements are common between third-party logistics services providers and their partnering manufacturing companies [CL00]. These contracts guarantee that the warehouses deliver the orders to the distribution centres in a ‘next day’ dispatch time. It also guarantees TDD for outbound deliveries to customers. Such an arrangement is useful for effective Just-in-Time (JIT) manufacturing. Therefore, the distribution centres can act as transshipment points that are not allowed to keep normal stock as traditional stores as in the previous models. The stockout is also not allowed due to using such arrangement.

7.2. Experiments Designs

In this chapter, two optimal uncoordinated and coordination distribution strategies are designed and conducted based on the above approach (VMI). For designing these experiments, some assumptions have been considered:

- The inventory decisions are taken at the warehouses.
- The customer orders are filled completely.
- There are daily deliveries between the warehouses and distribution centers.
- The filling of customer orders is based on a first-in-first-out (FIFO) rule.
- The number of distribution centers that have been considered are twenty four (DC's =24)
- Stockout is not allowed.
- Distribution centres are not allowed to keep normal stock.

The two distribution strategies are as follows:

- UCS-V-Expt: Uncoordinated Strategy with VMI approach experiment.
- CS-V-Expt: Coordination Strategy with VMI approach experiment

7.2.1. VMI-Programs Uncoordinated Strategy - (UCS-V-Expt):

The objective of this strategy is to show how the VMI performs better than the other distribution strategies in improving the system performance of supply chain. As mentioned above, this experiment is designed based on the VMI approach. In this experiment the inventories decisions are taken at the warehouses and the distribution centers are transshipment points. The warehouses use the demand information of distribution to make replenishments and deliver only the orders of downstream locations (DC's) in the next day as stated by the TDD agreement (shipment without consolidation).

7.2.2. VMI-Programs Coordination Strategy - (CS-V-Expt):

The goal of this strategy is to show, the benefit of using consolidation concepts with the VMI approach to make more active and attractive coordination between transportation and inventory decisions that would result in optimization of the supply chain system performance. The design of the experiment is described as follows:

The VMI uncoordinated strategy (UCS-V-Expt) is integrated with all consolidation concepts used in the previous chapters (5 and 6) to optimize system performance. From this integration, nine experiments are generated as follows:

1. VMI Model with ABC-Articles experiment (CS-V-ABC-Expt 1).
2. VMI Model with A-Articles experiment (CS-V-A-Expt 2).
3. VMI Model with C-Articles experiment (CS-V-C-Expt 3).
4. VMI Model with Z-Articles experiment (CS-V-Z-Expt 4).

5. VMI Model with New-ABC-Articles experiment (CS-V-N-ABC-Expt 5).
6. VMI Model with New-A-Articles experiment (CS-V-N-A-Expt 6).
7. VMI Model with New-C-Articles experiment (CS-V-N-C-Expt 7).
8. VMI Model with 2-Days Forecasted Demand experiment (CS-V-2D-Expt 8).
9. VMI Model with 4-Days Forecasted Demand experiment (CS-V-4D-Expt 9).

The general structure of designing the nine coordination strategies by using VMI programs model will be summarized in Table 7.1.

Table 7. 1 General Structure of Coordination Strategies Design Using a New ABC Classification

Expt-Name	Uncoordinated Strategy Expt.	Consolidation Concept								
	UCS-V-Expt	ABC	A	C	Z	New-ABC	New-A	New-C	2D	4D
CS-V-Expt	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

✓	Integrated
-	Not Integrated

7.3. Experimental Simulation Results and analysis

In this section, all the simulation results for one year from the uncoordinated and coordination strategies of VMI model are presented and analyzed. Most of the measures of performance from the previous chapters are also used. The measures of service level (AOLFR and AOFR) are not considered.

7.3.1. Results and Analysis of UCS-V-Expt Uncoordinated Strategy

After the run of simulation for one year, the results of the experiment (UCS-V-Expt) are collected and compared with the results of the uncoordinated strategies of Chapter 4. Table 7.2, Figure 7.1 and Figure 7.2 show the measures of performance of UCS-V-Expt strategy and the uncoordinated strategies.

Table 7. 2 Measures of Performance for Each Experiments Sorted in Descending Order of the Total Logistics Cost

Experiments	TTC	TIHC	TLC
UCS-Expt 10	$8.150.344,06	$340.914,26	$8.491.258,32
UCS-Expt 5	$8.139.476,97	$340.781,80	$8.480.258,77
UCS-Expt 2	$8.149.488,60	$321.158,15	$8.470.646,75
UCS-Expt 3	$8.125.338,06	$344.206,49	$8.469.544,55
UCS-Expt 9	$8.139.772,59	$317.015,50	$8.456.788,09
UCS-Expt 7	$8.124.646,65	$266.363,19	$8.391.009,84
UCS-Expt 1	$8.114.944,57	$276.000,10	$8.390.944,67
UCS-Expt 8	$8.146.816,06	$238.005,21	$8.384.821,27
UCS-Expt 6	$8.116.662,30	$233.927,36	$8.350.589,66
UCS-Expt 4	$8.109.584,95	$205.694,79	$8.315.279,74
UCS-V-Expt	$8.165.469,71	$60.699,59	$8.226.169,30

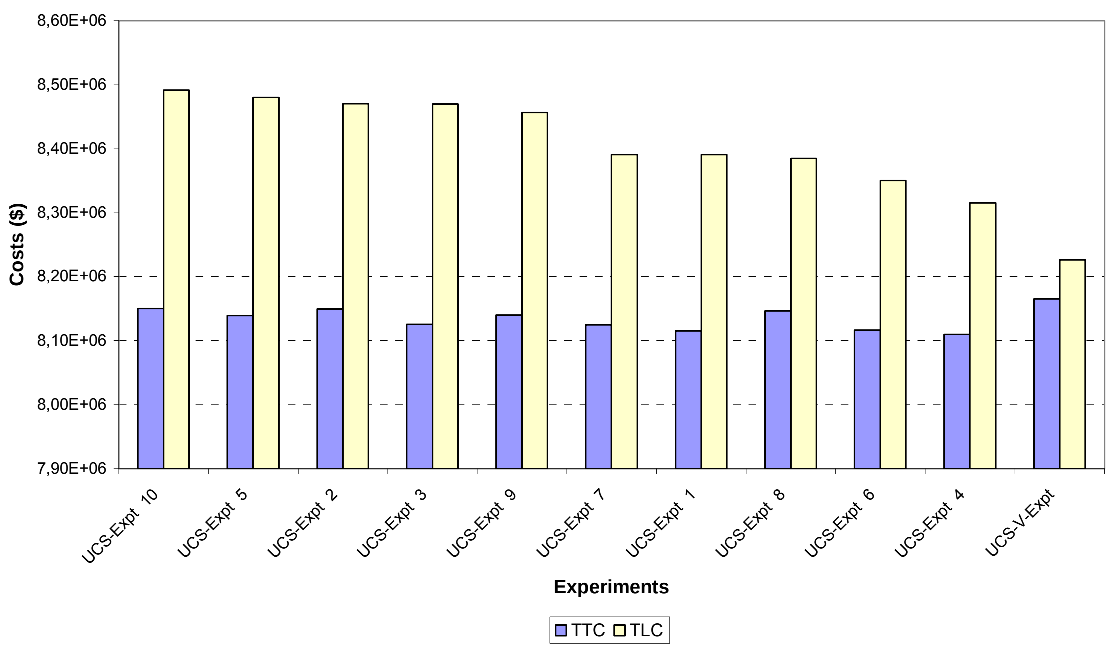

Figure 7. 1 Total Logistics Costs and Transportation Cost for Each Experiment

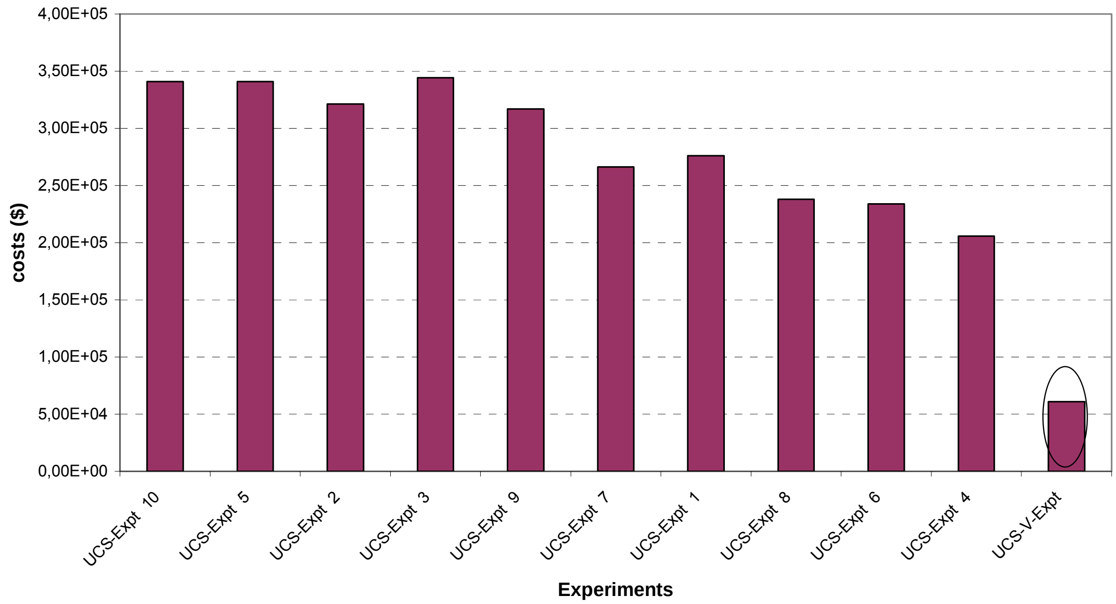

Figure 7. 2 Total Average Inventory Cost for Each Experiment

From the investigation of the results, the VMI-Programs uncoordinated strategy performs better than the uncoordinated strategies in terms of the total logistics costs. This is mainly due to the reduction in the inventory costs by this approach that result from using TDD contracts and reading the information of demand from the downstream directly. The certainty of delivering the customer with certain time (TDD) and the integration of information reduce the variation of demand. Based on this it is not necessary to buffer variations in demand and lead time which is treated by increasing the stock level (safety stock).

- The uncoordinated strategies perform very well in terms of transportation cost. The reason behind this is that in the uncoordinated strategies, the distribution centers keep stocks that minimize the number of replenishments. The size of shipment is also greater than the size of shipment in the VMI-programs model. This gives more of a chance for getting saving from the discount offered by the transportation rate. So finally, the decision to choose between them mainly depends on the cost structure of the enterprise.

7.3.2. Results and Analysis of CS-V-Expt Coordination Strategy

As in the previous model, the simulation study for one year is conducted and measures of performance for the ten experiments are estimated to compare between the VMI-Programs uncoordinated strategy (as a base) and VMI-Programs coordination strategy. The results of the comparison are illustrated in Table 7.3, Figure 7.3 and Figure 7.4. These comparisons are to prove that using the VMI concept optimizes the system performance especially if it is coordinated with transportation decisions (Consolidation concepts).

Table 7. 3 Measures of Performance for Each Experiments Sorted in Ascending Order of Total Logistics Cost

Experiments	TTC	TIHC	TLC
CS-V-4D-Expt 9	$7.310.720,73	$103.310,88	$7.414.031,61
CS-V-2D-Expt 8	$7.427.079,46	$77.471,24	$7.504.550,70
UCS-V-Expt*	$8.165.469,71	$60.699,59	$8.226.169,30
CS-V-N-ABC-Expt 5	$9.465.710,35	$3.136.988,01	$12.602.698,36
CS-V-ABC-Expt 1	$9.775.895,37	$3.572.044,89	$13.347.940,26
CS-V-N-A-Expt 6	$10.732.203,99	$4.248.779,40	$14.980.983,39
CS-V-A-Expt 2	$11.432.887,19	$5.221.359,74	$16.654.246,93
CS-V-Z-Expt 4	$11.962.377,27	$6.054.198,93	$18.016.576,20
CS-V-C-Expt 3	$12.316.324,81	$6.568.157,88	$18.884.482,69
CS-V-N-C-Expt 7	$12.319.218,11	$6.566.795,71	$18.886.013,82

* Base Experiment

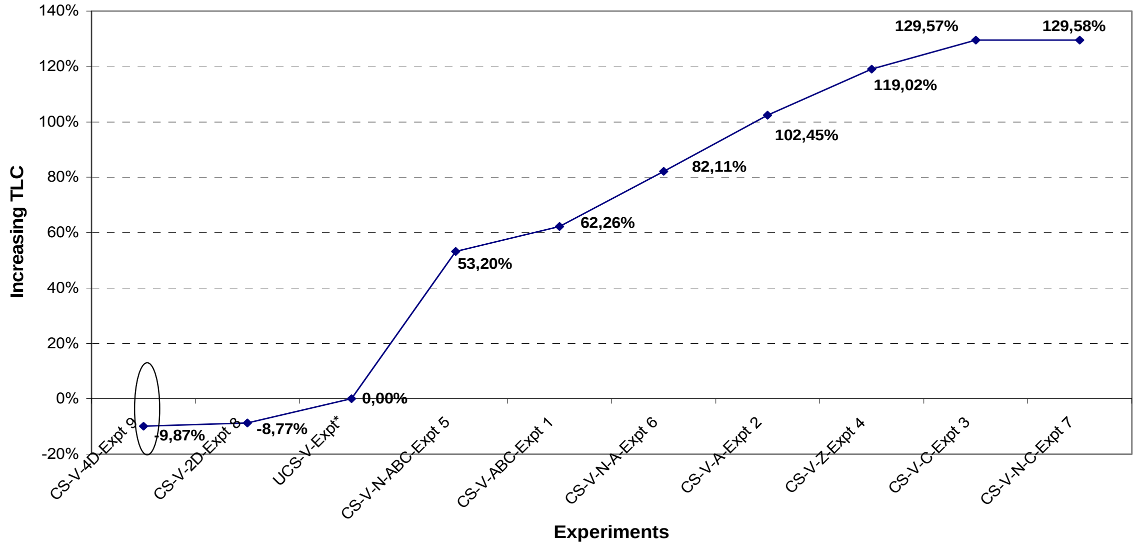

Figure 7. 3 Percentage of Increasing Total Logistics Costs by Each Experiment

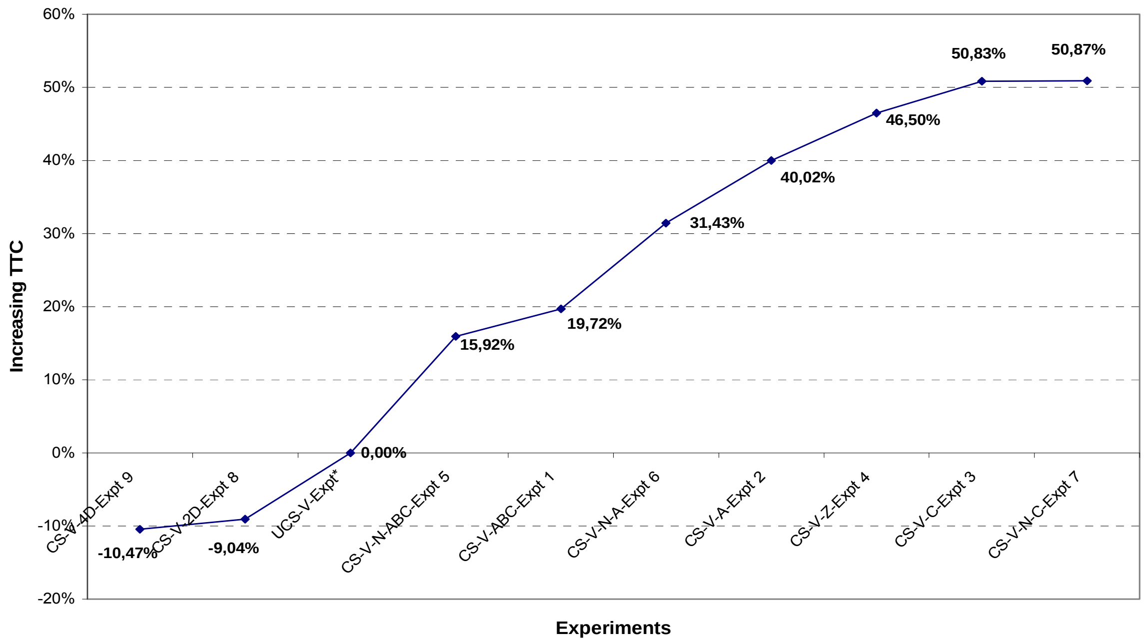

Figure 7. 4 Percentage of Increasing Total Transportation Cost by Each Experiment

From the previous table and figures, the VMI-Programs coordination strategy performs better than the VMI-Programs uncoordinated strategy, especially when 4-Days Forecasted Demand consolidation concept is used. This consolidation concept improves the system performance. The percentage of reduced total logistics costs of CS-V-4D-Expt 9 strategy is approximately **9%** lower than that of UCS-V-Expt strategy. The percentage of reduced total Transportation costs of CS-V-4D-Expt 9 strategy is also approximately **10%** lower than that of the UCS-V-Expt strategy (Figure 7.3 and 7.4).

- For the Item consolidation concepts, they are not attractive to use for constructing the coordination strategy. This is due to the complex structure of transportation rate (Figures 5.16, 5.17, 5.18, and 5.19) and the huge size of consolidated quantity. To explain that the total number of tours and the shipped quantity from the warehouses to the distribution centers for one year have been calculated. Table 7.4 and Figure 7.5 show the total number of tours and the shipped quantity of selected optimal coordination strategies and the VMI-Programs uncoordinated strategy.

Table 7. 4 Total Numbers of Tours and Shipped Quantity (Pallets) for Each Selected Experiment

Experiments	Total Number of Tours	Total Shipped Quantity (pallets)
UCS-V-Expt*	41650	889887
CS-V-N-A-Expt 6	37662	1175433
CS-V-ABC-Expt 1	36004	1119838
CS-V-N-ABC-Expt 5	35241	1090222
CS-V-4D-Expt 9	30782	889988

* Base Experiment

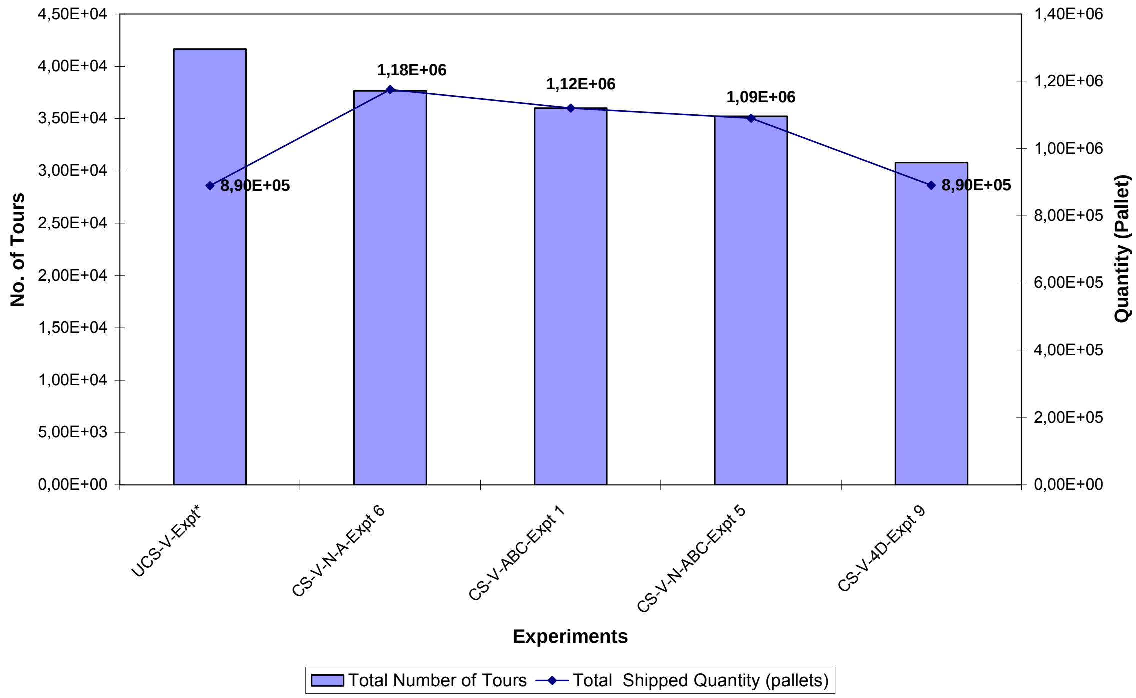

Figure 7. 5 Total Number of Tours and Shipped Quantities (Pallets) for Each Selected Experiment

From Table 7.4, the number of tours is reduced by using consolidation concepts but the shipped quantity is increased hugely, specially with the Item classification consolidation concepts. The increase in the shipped quantities causes an increase in the average ending inventory and the transportation quantity which finally increases the total logistics cost as shown in the previous table and figures (Table 7.3., Figure 7.3 and Figure 7.4). For example, if the dispatching cost of truck is considered, it would be more attractive to use the Item classification consolidation concepts (for example, the New-ABC-Articles).

1. Also from Table 7.4 and Figure 7.5, it is clear that the new item classification performs better than the old item classification as a consolidation concept with the VMI-Model.

Another comparison study is done to compare between (UCS-V-Expt) strategy, CS-V-4D-Expt 9 strategy and all the coordination strategies in Chapter 5 which use (4-Days Forecasted Demand) consolidation concept. The aim of this study is to enhance the use of the VMI approach in the supply chain for coordinating the inventory and transportation decisions rather than the other coordination strategies.

The experiment CSL (90%) ABC Item with 4-Days Forecasted Demand coordination strategy (CS7-4D-Expt6) has been taken as a base to be compared with the other experiments. The measures of performance and the percentage of the difference in logistics costs are calculated for each experiment and illustrated in Table 7.5, Figures 7.6, 7.7, and 7.8. These measures of performance are sorted in descending order of the total logistics cost.

Table 7. 5 Measures of Performance for Selected Experiments Sorted in Descending Order of Total Logistics Cost

Experiments	TTC	TIHC	TLC
CS7-4D-Expt6*	$8.128.735,31	$338.034,68	$8.466.769,99
CS2-4D-Expt6	$8.132.842,11	$318.010,96	$8.450.853,07
CS3-4D-Expt6	$8.103.591,95	$340.000,96	$8.443.592,91
CS6-4D-Expt6	$8.113.603,89	$312.881,40	$8.426.485,29
CS1-4D-Expt6	$8.039.851,27	$268.930,82	$8.308.782,09
UCS-V-Expt	$8.165.469,71	$60.699,59	$8.226.169,30
CS5-4D-Expt4	$7.965.066,71	$208.856,65	$8.173.923,36
CS4-4D-Expt4	$7.928.724,62	$180.621,99	$8.109.346,61
CS-V-4D-Expt 9	$7.310.720,73	$103.310,88	$7.414.031,61

* Base Experiment

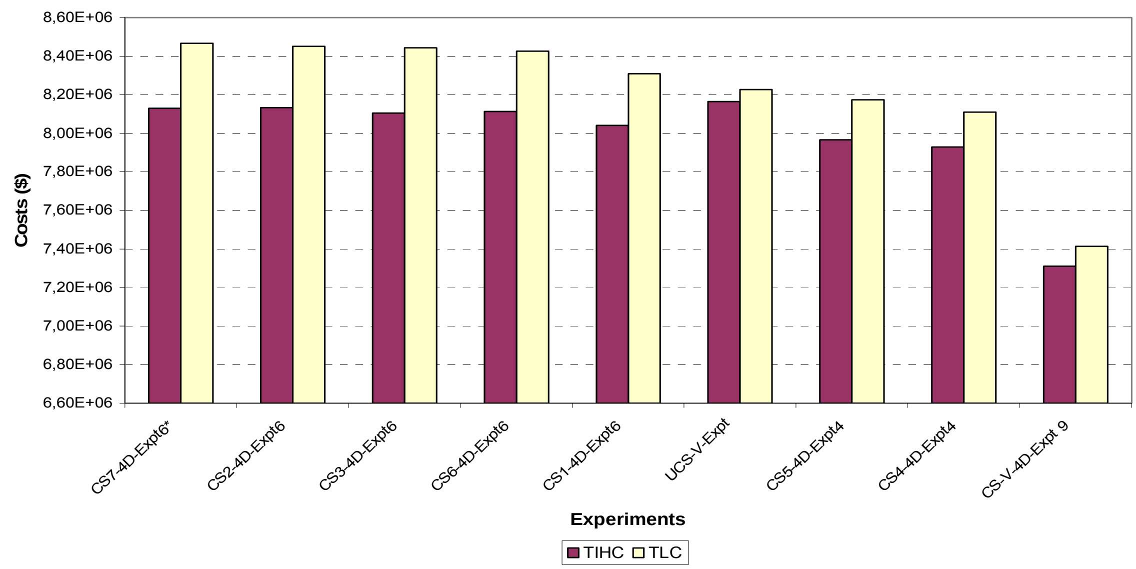

Figure 7. 6 Total Logistics Costs and Transportation Cost for the Selected Experiments

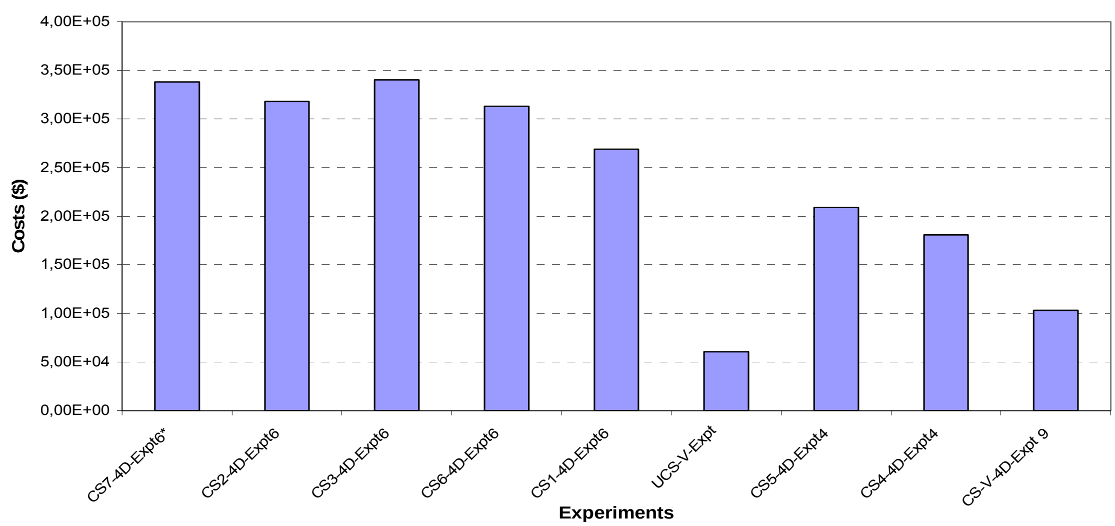

Figure 7. 7 Total Average Inventory Cost for the Selected Experiments

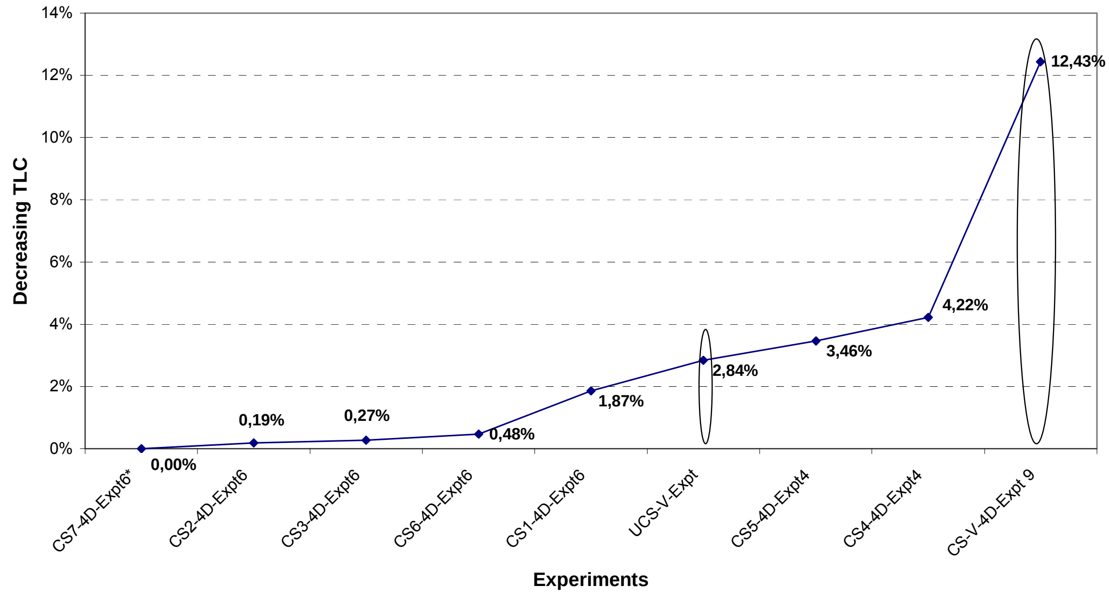

Figure 7. 8 Percentage of Decreased Total Logistics Costs for the Selected Experiments

From the previous table and the figures, the following conclusions can be made:

- The (UCS-V-Expt) strategy reduces the total logistics costs by approximately **3%** as compared to the CS7-4D-Expt6 strategy (Base).
- The CS-V-4D-Expt 9 strategy reduces the total logistics costs by approximately **12%** as compared to the CS7-4D-Expt6 strategy (Base).
- The CS-V-4D-Expt 9 strategy is the optimal strategy in terms of total logistics costs. Furthermore, this strategy has the minimum transportation cost as compared to all the strategies discussed in this thesis.

7.3.3. Truck Utilization Analysis

As mentioned in the analysis of the results of the UCS-V-Expt Strategy, the transportation cost of the VMI-Programs uncoordinated strategy is higher than the transportation cost of all the uncoordinated strategies in Chapter 4. To get a deeper insight into the reason behind the increasing of the transportation cost in

UCS-V-Expt strategy and also to justify the necessity of applying the coordination strategies with the VMI-model, the truck utilization between each the upstream location (Warehouse) and the downstream location (only 19RDCs) of the UCS-V-Expt Strategy have been calculated and are presented in Figure 7.9.

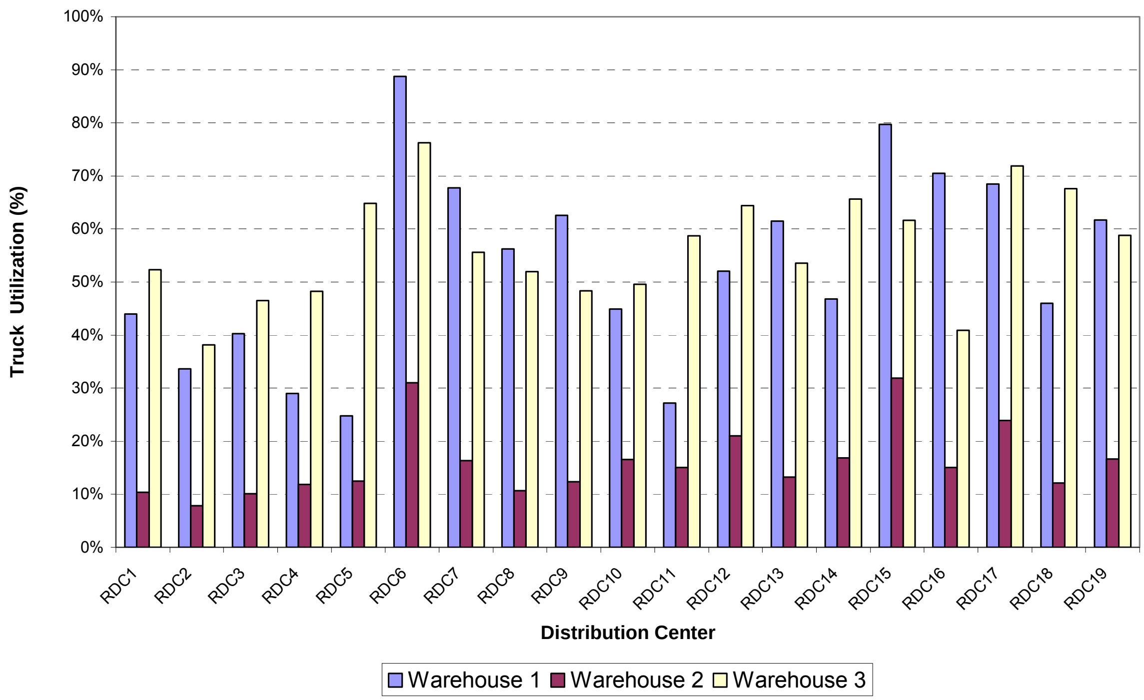

Figure 7. 9 Truck Utilization between Upstream Locations and Downstream Locations for UCS-V-Expt Strategy

The above figure shows that, the truck utilization between the warehouses and the distribution centres is very low. The average truck utilization for this strategy is approximately 42%. The low value of truck utilization would be improved by applying the coordination strategies (CS-V-Expt) as discussed below.

To prove the effectiveness of applying the coordination strategies with VMI concept for improving the truck utilization, the VMI Model With 4-Days Forecasted Demand consolidation concept (CS-V-4D-Expt 9) is selected, the truck utilization between each upstream location (Warehouse) and the downstream location (only 19RDCs) have been calculated and presented in Figure 7.10 .

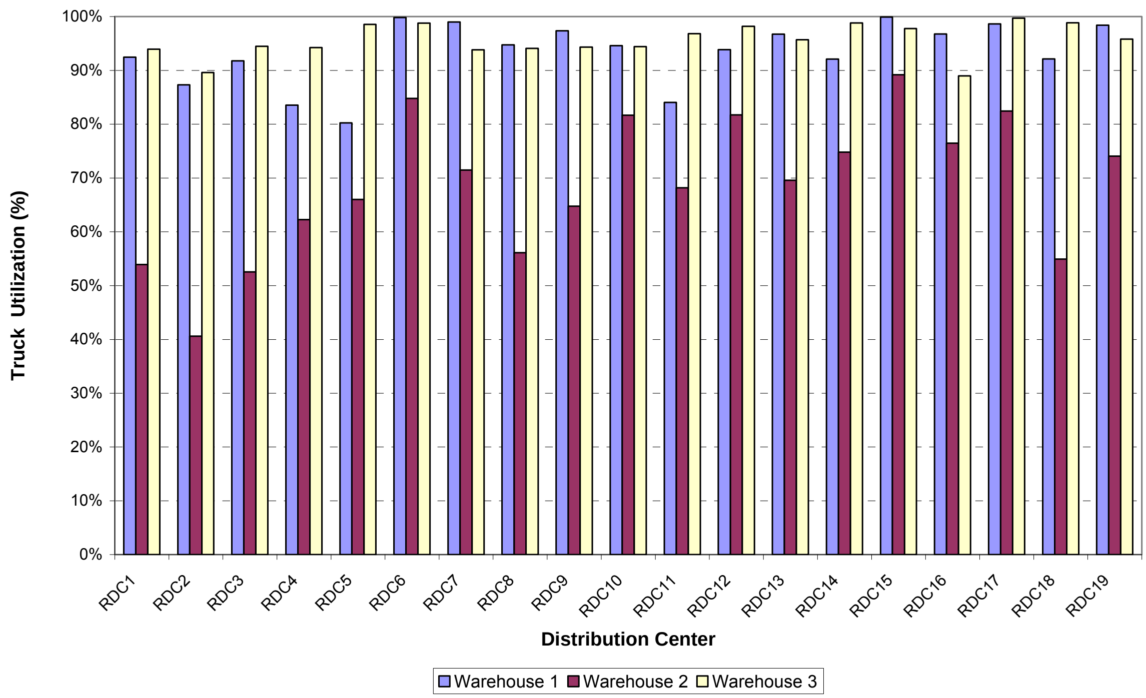

Figure 7. 10 Truck Utilization between Upstream Locations and Downstream Locations for CS-V-4D-Expt 9 Strategy

As can be seen from Figure 7.10, the 4-Days Forecasted Demand consolidation concept can guarantee that the truck utilization in some cases is 100% (a full truckload) and on average is more than 85%. The truck utilization of this strategy (CS-V-4D-Expt 9) is approximately 43% higher than that of UCS-V-Expt Strategy.

7.3.4. Lower Bound Transportation Cost Analysis

As mentioned before, the CS-V-4D-Expt 9 strategy is the optimal strategy in terms of total transportation costs (Table7.5). Furthermore, to investigate how much (percentage) of the total transportation cost of this strategy is increased as compared to the lower bound total transportation costs, an experiment is conducted. In this experiment, the CS-V-4D-Expt 9 strategy is repeated under a new assumption that it has the minimum transportation cost as compared to all the strategies discussed so far. The assumption is due to the fact that the transportation tariff (minimum cost) is offered for a full truck load between each warehouse and distribution centre and it will be used as the transportation cost in this experiment. The results of this experiment (Lower Bound Transportation Cost) are compared with the results of the CS-V-4D-Expt 9 strategy and presented in Table 7.6.

Table 7. 6 Measures of Performance of Lower Bound Transportation Cost Experiment

Experiments	TTC	TIHC	TLC
CS-V-4D-Expt 9	$7.310.720,73	$103.310,88	$7.414.031,61
Lower Bound Transportation Cost _Expt	$7.193.362,65	$103.310,88	$7.296.673,53

The results in the above table show that, the total transportation cost of the optimal strategy (CS-V-4D-Expt 9) is approximately only 2% higher than the lower bound transportation cost experiment. This means that, the optimal strategy (CS-V-4D-Expt 9) achieves 98% of the lower bound of total transportation cost.

Conclusion:

Referring to the above results and analysis, the following conclusions can be made:

- In all cases the VMI approach performs better than the other coordination strategies for optimizing supply chain performance.
- The VMI approach can efficiently reduces the inventory-carrying costs.
- The VMI approach with 4-Days Forecasted Demand consolidation concept is an optimal coordination distribution strategy.

8. Conclusions and Future Work

8.1. Conclusions

Throughout this dissertation, many conclusions have been made. These conclusions are summarized as follows:

1- The correct selection of item classification (More Frequent Items) and estimation of consolidated load for each item are the keys for getting the optimal coordination strategy.
2- More frequent items should be included in all consolidated shipments.
3- The optimal size of the consolidated shipment for each item should be between (20-80%) of consumption rate to increase the replenishment interval time of more items with minimum residual stock.
4- The truck capacity should be allocated to all items so as to maximize the time to next replenishment.
5- The classification of items is a tool for good design control strategy in distribution problems.
6- A two or more dimensional classification approach can help in improving the measure of performance as a very good strategy can be designed in the supply chain.
7- The classification and allocation of items has effect on the total logistic costs. Allocation of inventory strategies can give attractive savings on total logistic cost especially when only the Item Fill Rate is considered.
8- More measures of performance should be used to give more insights on the performance of the system and on the right decisions to be taken.
9- Well designed coordination strategy can perform better than uncoordinated strategy and reduces the systemwide costs (logistic costs) efficiently.

10- Understanding of residual stock behavior can help to achieve more powerful coordination between the transportation and inventory functions in supply chain management.

11- The developed consolidation concepts can guarantee that the order quantities will generate a full truckload.

12- Companies have good opportunities to improve performance, to reduce cost and to increase service level by coordinating the supply chain.

13- VMI concept would be convenient for the supply chain as a whole.

14- In complex systems with high demand variations, it is difficult to design powerful distribution strategy.

15- More integration of information between upstream locations and downstream locations is required. This helps to reduce the effect of demand variations and make good forecasting to design very powerful coordination strategy that would improve system performances.

16- Information availability is the key element for integration and coordination the different supply chain stages.

17- Sharing of information among the supply chain partners is a fundamental requirement for effective supply chain management.

18- It is clear that the implementation of advanced information technology could reduce systemwide cost.

Industries realize that managing information flow is as important as managing material flow in the supply chain. Simulation plays an important role for building such complex integrated systems. Supply chains are too complicated to analyze through analytical modeling. Simulation models can represent the uncertainty, variability and coordinating problems in the supply chains in an effective way.

19- Simulation is a powerful tool for studying supply chains.

20- Using simulation to evaluate supply chain strategies can lead to better decisions, saving money, decreased inventory, and improved customer service.

8.2. Future Work

There are many opportunities and several ways in which the various concepts presented in this research can be extended in the future. These ways are:

- More complex and real transportation cost structures
- More experiments and strategies. For example, VMI approach with 6-Days Forecasted Demand consolidation concept
- Different network structures
- More common inventory policies (echelon stock concept)
- Non-direct shipment between different locations (Vehicle Routing Problem)
- Optimal strategy for each downstream location to see the effect of decentralization strategies on supply chain coordination
- More item classification criteria to make more sensitive analysis of item characteristics which results in appropriate design of distribution and coordination strategies
- New shipment consolidation concept that would combine the quantity and time controlling criteria for designing the consolidated shipment

Further work has already been started and it is in the beginning stage of expanding the simulation model presented in this study to investigate the application of non-direct shipment and the impact of finding the right inventory policy with the vehicle scheduling (Routing) rules on the performance of supply chains will be investigated. This problem is called the Inventory Routing Problem (IRP) in the literature.

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